STRUCTURAL DESIGN OF SAF STILLING BASINS

PREFACE

This technical release continues the effort to produce design aids which can serve to improve the efficiency and quality of design work. The technical release deals with the structural design of SAF stilling basins. TR-50 deals with the structural design of rectangular channels. Taken together, these two technical releases provide a means of obtaining structural designs for essentially all sections of ordinary, straight inlet, chute spillways on earth foundations. This material should be useful to both planning and design engineers since either preliminary or detail designs may be obtained.

A draft of the subject technical release dated July, 1974, was sent to the Engineering and Watershed Planning Unit Design Engineers for their review and comment.

This technical release was prepared by Mr. Edwin S. Alling, Head, Design Unit, Design Branch at Hyattsville, Maryland. He also wrote the computer program.

TECHNICAL RELEASE
NUMBER 54

STRUCTURAL DESIGN OF SAF STILLING BASINS

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NOMENCLATURE

Not all nomenclature is listed. Hopefully the meaning of any unlisted nomenclature may be ascertained from that shown. Trailing letters U or D are used with some variables. This signifies variables associated with the upstream or downstream portion of type (B) stilling basins.

A	$\equiv$ required reinforcing steel area
A_1	$\equiv$ area of right section at one end of prismatoid
A_2	$\equiv$ area of right section at opposite end of prismatoid
A_m	$\equiv$ area of mid-section of prismatoid
ARM	$\equiv$ distance from B-line to underside of upstream section; moment arm of wingwall-to-basin tie
ATIE	$\equiv$ required steel area of wingwall-to-basin tie
BACK	$\equiv$ distance used to define the wingwall footing extension back to the sidewall
BASEL	$\equiv$ horizontal length of basin projected bearing area
BAT	$\equiv$ rate of batter of inside surface of lower part of sidewall
BDN	$\equiv$ footing projection at downstream end of wingwall
BUP	$\equiv$ footing projection at upstream end of wingwall-section at articulation joint
b	$\equiv$ width of reinforced concrete member
CB	$\equiv$ direct compressive force in the floor slab between sidewalls
CC	$\equiv$ construction condition, a loading condition investigated in wingwall design
CF	$\equiv$ direct compressive force in the footing projection
CFSC	$\equiv$ coefficient of friction, soil to concrete
D	$\equiv$ effective depth of concrete section; diameter of reinforcing bar
D1	$\equiv$ entrance depth of water to SAF stilling basin
D2	$\equiv$ the sequent depth to depth D1
DS	$\equiv$ a sequent depth
DW	$\equiv$ depth of water in basin; tailwater depth in wingwall design
DWD	$= DW - D/12$
DZ	$\equiv$ depth of water in basin above section under consideration
E	$\equiv$ eccentricity of VNET
F_1	$\equiv$ Froude's number $= V1^2/gD1$
FBOT	$\equiv$ uniform tangential loading on bottom of pavement slab
FH1	$\equiv$ horizontal component of hydrostatic force due to HUP1
FH2	$\equiv$ horizontal component of hydrostatic force due to HUP2
FH2WD	$\equiv$ the part of FH2 x W carried by downstream portion of type (B) basin
FLOATR	$\equiv$ safety factor against flotation
FM	$\equiv$ force due to horizontal change in momentum
FM1	$\equiv$ momentum force at section of depth D1
FM2	$\equiv$ momentum force at section of depth HTW2
FS2	$= FH2 + FM$
FSLIDE	$\equiv$ resultant of the horizontal driving forces tending to cause sliding of the basin
FT1	$\equiv$ horizontal component of hydrostatic force due to HTW1

FTG	$\equiv$	footing projection
FTOP	$\equiv$	uniform tangential loading on top of pavement slab
F_{x_1}	$\equiv$	hydrostatic force due to depth D1
F_{x_2}	$\equiv$	hydrostatic force due to depth HTW2
f_c	$\equiv$	compressive stress in concrete
f_s	$\equiv$	stress in reinforcing steel

GB	$=$	GS - 62.4
GM	$\equiv$	moist unit weight of earthfill
GS	$\equiv$	saturated unit weight of earthfill
g	$=$	32.2 ft per $\sec^2$
HB	$\equiv$	earthfill height above top of floor of basin at downstream end of basin
HBD	$=$	HBW - D/12
HBn	$\equiv$	earthfill height at section n
HBW	$\equiv$	working value of height of earthfill
HBZ	$\equiv$	height of earthfill above section under consideration
HDIFF	$=$	(HBW - HWW) or (HBW - HUW)

HN	$\equiv$	vertical component of distance N
HNET	$\equiv$	net horizontal force per unit length acting on wingwall design section
HS	$\equiv$	vertical projection of inclined floor slab
HSHV	$=$	(HSW - HV) or (J - HV)
HSn	$\equiv$	height of section n
HSW	$\equiv$	working value of height of section
HTmn	$\equiv$	tailwater depth at section n for load condition m
HTW	$\equiv$	depth of toewall below top of floor of basin
HTW1	$\equiv$	tailwater depth above top of floor of basin for load condition No. 1
HUP	$\equiv$	uplift head above top of floor of basin for load condition under consideration

HUP1	$\equiv$	uplift head above top of floor of basin for load condition No. 1
HUmn	$\equiv$	uplift head at section n for load condition m
HUW	$\equiv$	working value of uplift head at section under consideration
HV	$\equiv$	the distance over which the inside surface of the sidewall is vertical
HVZ	$\equiv$	battered height of sidewall above section under consideration
HW	$\equiv$	uplift head above top of wingwall footing at the articulation joint for load condition under investigation
HWALL	$\equiv$	shear at bottom of sidewall at section under investigation
HWD	$=$	HWW - D/12
HWW	$\equiv$	working value of water head on outside of sidewall
HWZ	$\equiv$	height of water head above section under consideration

HX	$\equiv$	depth of water over top of pavement slab at XDN from downstream end
h	$\equiv$	perpendicular distance between right end sections
ILC	$\equiv$	intermediate load condition used in wingwall design
J	$\equiv$	height of sidewall above top of floor of basin
KO	$\equiv$	lateral earth pressure ratio
LB	$\equiv$	length of SAF stilling basin
LBOT	$\equiv$	length of bottom of type (A) basin

LC#1 $\equiv$ load condition No. 1
LEVEL $\equiv$ distance used to locate the wingwall articulation joint with respect to the corner of the sidewall
LN $\equiv$ horizontal component of distance N

LS $\equiv$ horizontal projection of inclined floor slab
LTOP $\equiv$ length of top of sidewall of type (A) basin
LTOT $\equiv$ overall length of type (B) and (C) basins
M $\equiv$ bending moment; moment of forces about some moment center
MA $\equiv$ moment of forces about the A-line of type (C) basins
MAXFTG $\equiv$ maximum acceptable sidewall footing projection
MB $\equiv$ moment of forces about the B-line of type (C) basins
MC $\equiv$ bending moment at the center of the floor slab
MDN $\equiv$ resultant moment of the forces on the downstream portion about the hinge
MP $\equiv$ bending moment in pavement slab

M_s $\equiv$ equivalent moment, moment about axis at the tension steel
MTIE $\equiv$ bending moment used to obtain ATIE at wingwall-to-basin tie
MUP $\equiv$ resultant moment of the forces on the upstream portion about the hinge
MZ $\equiv$ bending moment at section under consideration
N $\equiv$ height of sidewalls at upstream end section; direct compressive force in sidewall
NLAT $\equiv$ bearing force between pavement slab and retaining wall portion
NWALL $\equiv$ direct force of wingwall
NZ $\equiv$ direct compressive force at section under consideration
PALLOW $\equiv$ maximum allowable bearing (contact) pressure
PARM $\equiv$ distance between PWALL and vertical face of sidewall

PAVER $\equiv$ average bearing pressure
PB $\equiv$ bearing pressure at section under investigation
PBG $\equiv$ bearing pressure at break-in-grade
PBH $\equiv$ bearing pressure at heel of retaining wall portion
PBT $\equiv$ bearing pressure at toe of retaining wall portion
PDH $\equiv$ bearing pressure at heel of downstream end section
PDN $\equiv$ bearing pressure at downstream end section
PDT $\equiv$ bearing pressure at toe of downstream end section
PDW $\equiv$ water pressure in basin
PF $\equiv$ pressure on footing projection

PFn $\equiv$ pressure on footing projection at section n
PLONG $\equiv$ net longitudinal shearing forces assumed carried by sidewalls
PNET $\equiv$ net uniform loading between sidewalls
PTS $\equiv$ dead weight of floor slab
PUH $\equiv$ bearing pressure at heel of upstream end section
PUP $\equiv$ bearing pressure at upstream end section
PUT $\equiv$ bearing pressure at toe of upstream end section
PUW $\equiv$ uplift pressure on underside of slab
PWALL $\equiv$ direct force of sidewall
PX $\equiv$ bearing pressure on pavement slab at XDN from downstream end

pcf $\equiv$ pounds per cubic foot
psf $\equiv$ pounds per square foot

p_t ≡ temperature and shrinkage steel ratio
Q   ≡ SAF stilling basin discharge
QUANT   ≡ quantity, volume of stilling basin or associated wingwalls
q   ≡ unit discharge
S   ≡ maximum allowable spacing of reinforcing steel
SDOWN   ≡ sum of all downward forces acting on a basin or portion
SLIDER   ≡ safety factor against sliding
SUP   ≡ sum of all uplift forces acting on a basin or portion

SZ   ≡ maximum allowable spacing of reinforcing steel at section under consideration
T   ≡ required thickness
T'   ≡ required thickness at bottom of section due to T
T"   = HSHV x BAT
TABn   ≡ required thickness at bottom of section n
TADD   ≡ thickness to be added for cover
TB   ≡ thickness at bottom of sidewall
TBB   ≡ thickness at bottom of sidewall due to batter of inside face
TBV   ≡ thickness at bottom of sidewall exclusive of TBB
TM   ≡ required thickness due to bending moment

TPBG   ≡ thickness of pavement slab at break-in-grade
TPDN   ≡ thickness of pavement slab at downstream end section
TPUP   ≡ thickness of pavement slab at upstream end section
TS   ≡ thickness of slab; thickness required for shear
TSB   ≡ thickness required at bottom of sidewall due to required TV at HV
TSBG   ≡ slab thickness at break-in-grade
TSDN   ≡ slab thickness at downstream end section
TSR   ≡ required slab thickness
TSUP   ≡ slab thickness at upstream end section
TSV   ≡ thickness required at bottom of sidewall if HSW > HV

TT   ≡ thickness at top of widewall
TTW   ≡ thickness of toewall
TV   ≡ thickness of sidewall at HV from top of sidewall
TVn   ≡ required thickness of sidewall at HV from top of sidewall at section n
TW   ≡ working thickness of inclined floor slab at XBG from break-in-grade
TWF   ≡ thickness of wingwall footing
TWT   ≡ thickness of wingwall toewall
TWW   ≡ thickness of wingwall
TX   ≡ thickness of pavement slab at XDN from downstream end
ULONG   ≡ net longitudinal shearing forces assumed carried by floor or base slab

UX   ≡ uplift head on pavement slab at XDN from downstream end
u   ≡ flexural bond stress in concrete
V   ≡ concrete volume; shearing force at section under consideration
V1   ≡ entrance velocity of water to SAF stilling basin
V2   = V1 x D1/HTW2
VFTG   ≡ basin footing adjustment volume
VNET   = SDOWN - SUP

VP   ≡ shear in pavement slab

VRDN   ≡ resultant of the vertical forces acting on the downstream portion of type (B) basin

VRUP   ≡ resultant of the vertical forces acting on the upstream portion of type (B) basin

VTOE   ≡ toewall stub adjustment volume

VWALL   ≡ sidewall stub adjustment volume

VWING   ≡ volume of wingwalls exclusive of VFTG; resultant vertical force on wingwall

VWOAD   ≡ wingwall volume without adjustments

VZ   ≡ shear at section under consideration

v   ≡ shearing stress in concrete

W   ≡ width of SAF stilling basin

WDES   ≡ perpendicular distance from sidewall to the point where the outside edge of the wingwall footing intersects the plane of the downstream end section

WEXT   ≡ perpendicular distance from sidewall to the point on the outside edge of the wingwall footing that is in the plane of the articulation joint

WO   ≡ overall width of stilling basin

WOB   ≡ overall width of retaining wall base; overall width of wingwall base

WPROJ   ≡ wingwall projection, the perpendicular distance from the sidewall to the farthest point on the outside edge of the wingwall footing

WTWT   ≡ perpendicular distance from the sidewall to the point of intersection of wingwall toewall and plane of downstream end section

WWLB   ≡ perpendicular distance from the plane of the downstream end section to the point where the wingwall footing extended backward would intersect the outer edge of the sidewall

X   ≡ toe length of retaining wall base; distance from articulation joint to any vertical section of the wingwall

XBG   ≡ distance from break-in-grade to any vertical section of the inclined floor slab

XDN   ≡ distance from downstream end to any vertical section of the pavement slab or retaining wall portion

XP   ≡ width of pavement slab

YB   ≡ earthfill height above top of wingwall footing at distance X from articulation joint

YW   ≡ height of water on back face of the wingwall at distance X from articulation joint

Z   ≡ distance from moment center to VNET; distance from top of sidewall to section under consideration; distance from outer edge of wingwall footing to section under consideration

ZH   ≡ slope hypotenuse parameter

ZNS   ≡ slope parameter used to define an earthfill slope

ZNW   ≡ a slope parameter used to define an earthfill slope

ZPS   ≡ a slope parameter used to define an earthfill slope

ZS   ≡ slope parameter for inclined portion of stilling basin

γ = 62.4 pcf

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STRUCTURAL DESIGN OF SAF STILLING BASINS

Introduction

This technical release is concerned with the structural design of SAF
stilling basins. The hydraulic criteria for the dimensions of SAF out-
lets were developed by Fred W. Blaisdell, Hydraulic Engineer, ARS,
St. Anthony Falls Hydraulic Laboratory. These criteria are presented in
National Engineering Handbook, Section 14, "Chute Spillways," written by
Paul D. Doubt, formerly Head, Design Unit, SCS, Hyattsville, Maryland.

The material presented herein treats the structural design of rectangular
stilling basins having the general layout indicated on Engineering Stand-
ard Drawing ES-86, sheet 1, contained in NEH-14. This material does not
include hydraulic design which must preceed structural design. It is
assumed these structural designs will be obtained from computers although
the basic approach is independent of computer usage. Technical Release
No. 50, "Design of Rectangular Structural Channels," can be used to ob-
tain preliminary and detail structural designs of chute spillway sections
upstream of the stilling basin.

A computer program was written in FORTRAN for IBM 360 equipment to per-
form these SAF stilling basin designs. The program operates in two modes.
It will execute preliminary designs to aid the designer in selecting the
type of basin he desires to use in final design. The program will also
execute the detail design of specified basins. Concrete thicknesses and
distances are determined and steel requirements, in terms of required
area and maximum spacing, are evaluated at various locations. Actual
steel sizes and layouts are not selected, these are the prerogative of
the designer.

This technical release documents the criteria and procedures used in the
computer program, explains the input data required to obtain a design,
and illustrates computer output for preliminary and detail designs. At
the present time designs may be obtained by requests to the

> Head, Design Unit
> Engineering Division
> Soil Conservation Service
> Federal Center Building
> Hyattsville, Maryland 20782.

Input information which must be provided for each design run, is dis-
cussed under the section, "Computer Designs, Input."

Types of SAF Stilling Basins

Three types of SAF stilling basins are treated herein. Each type may be thought of as a structural variation of the SAF outlet shown on ES-86, sheet 1, and each uses the alternate joint detail given in that drawing. All types are assumed symmetrical in both construction and loading about the longitudinal centerline of the basin as well as about the vertical centerline of any transverse cross section. Each basin is designed for the two loading conditions described in the next section, and each must satisfy both flotation (uplift) requirements and sliding requirements. See Figures 1-3 for definition sketches of the three types of basins. These sketches present idealized stilling basins and do not show chute blocks, floor blocks, end sills, fillets on toewalls, upstream floor joint steps, or wingwalls. The wingwalls are omitted from these sketches for clarity and because the wingwall and basin proper are designed to act essentially independently of each other.

Any one of the three types of SAF stilling basin may be most advantageous for a particular set of design conditions. Because of the large number of parameters involved, it is often not readily apparent which type will be best in a given situation.

Type (A)

This type, see Figure 1, most closely approximates the SAF outlet of
ES-86. Structurally, the basin is a monolithic unit. The floor slab
thicknesses vary uniformly from the downstream end of the basin
to the break-in-grade, and from the break-in-grade to the upstream
end.
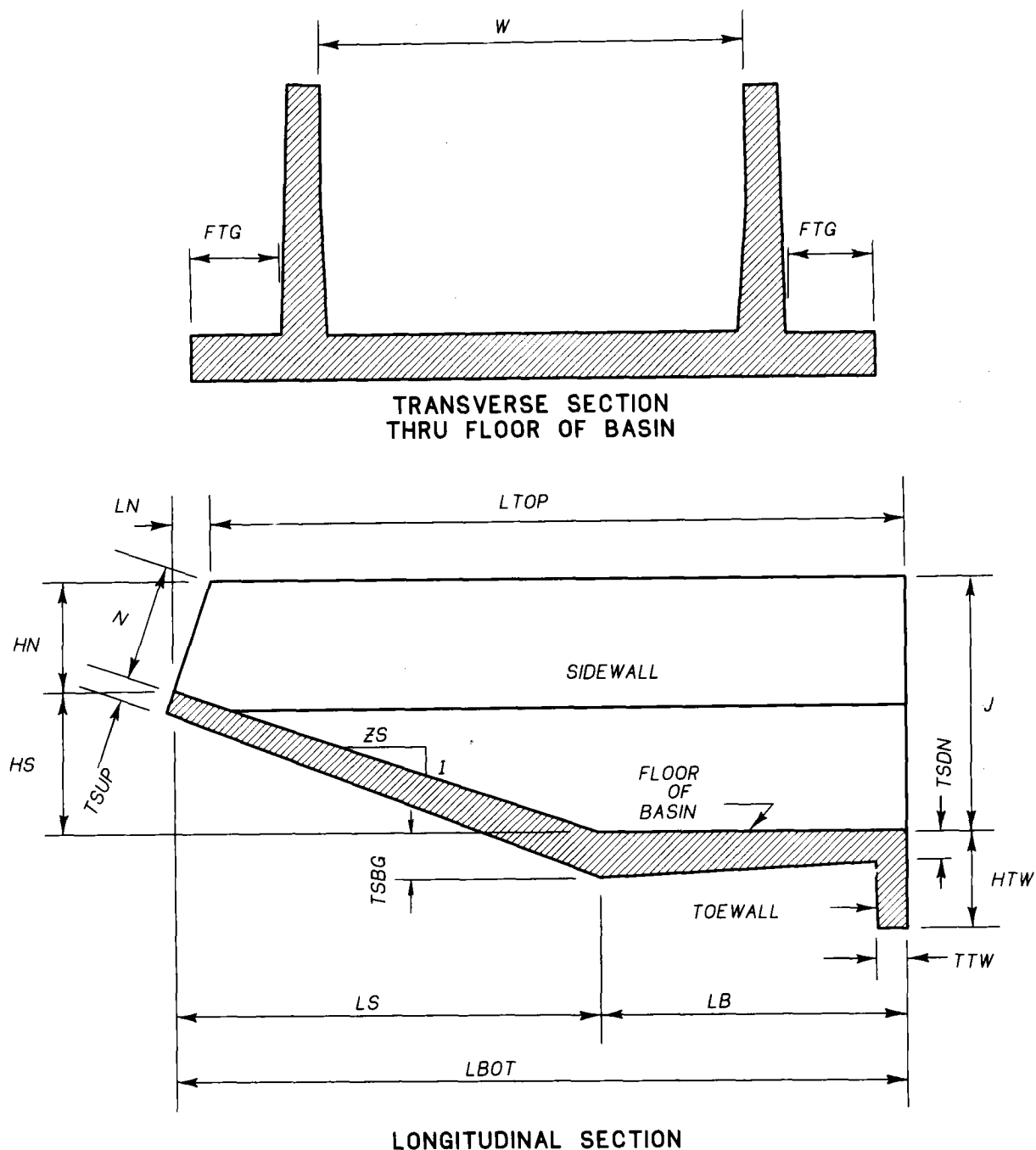
Figure 1. Type (A) SAF stilling basin

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Type (B)

This type, see Figure 2, has a transverse articulated joint at the break-in-grade. Some form of floor joint step is normally used at this joint. The upstream end section is vertical, rather than normal to the plane of the inclined floor slab. The doweled, transverse articulation joint makes the structural behavior of this type of SAF differ from that of type (A).

TRANSVERSE SECTION THRU FLOOR OF BASIN

LONGITUDINAL SECTION
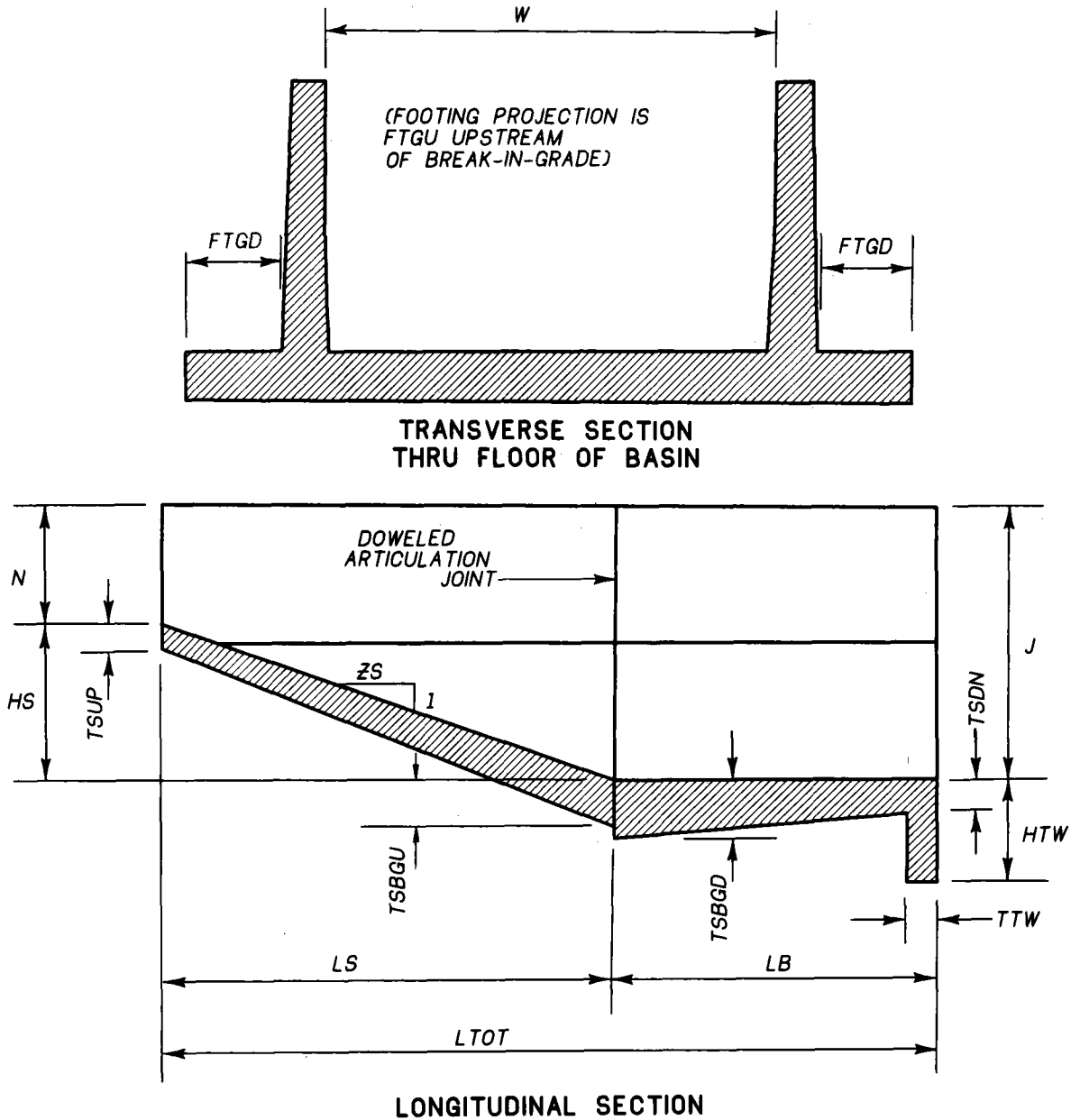
Figure 2. Type (B) SAF stilling basin

Type (C)

This type, see Figure 3, has independent retaining wall portions and pavement slab. The pavement slab resists any thrust imposed on it by the retaining wall portions. The most advantageous toe length, X, is determined in the design.
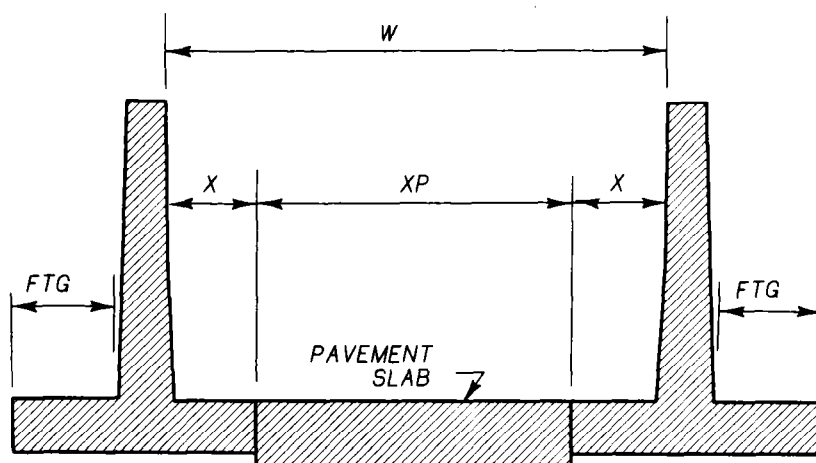
TRANSVERSE SECTION
THRU FLOOR OF BASIN
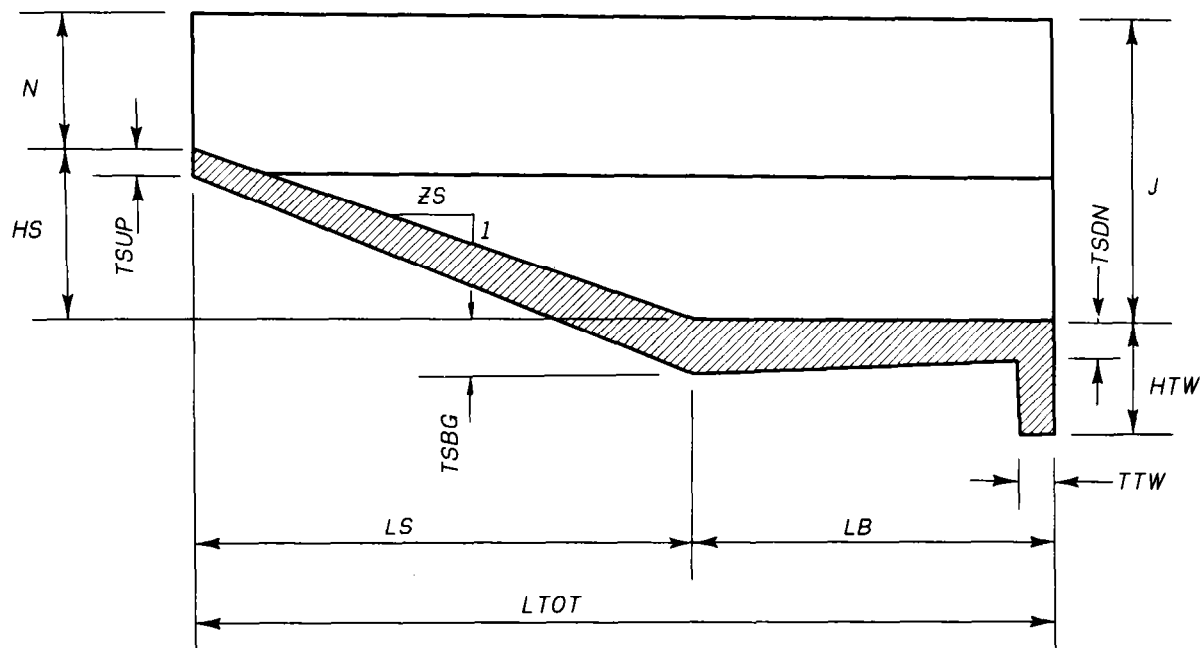
LONGITUDINAL SECTION
THRU RETAINING WALL PORTION

Figure 3. Type (C) SAF stilling basin

Wingwalls

The wingwall is articulated from the basin sidewall. Hence each wall acts as a simple cantilever. The wingwalls with their footings are not included in the stability analyses of the basin proper. Figure 4 gives the wingwall
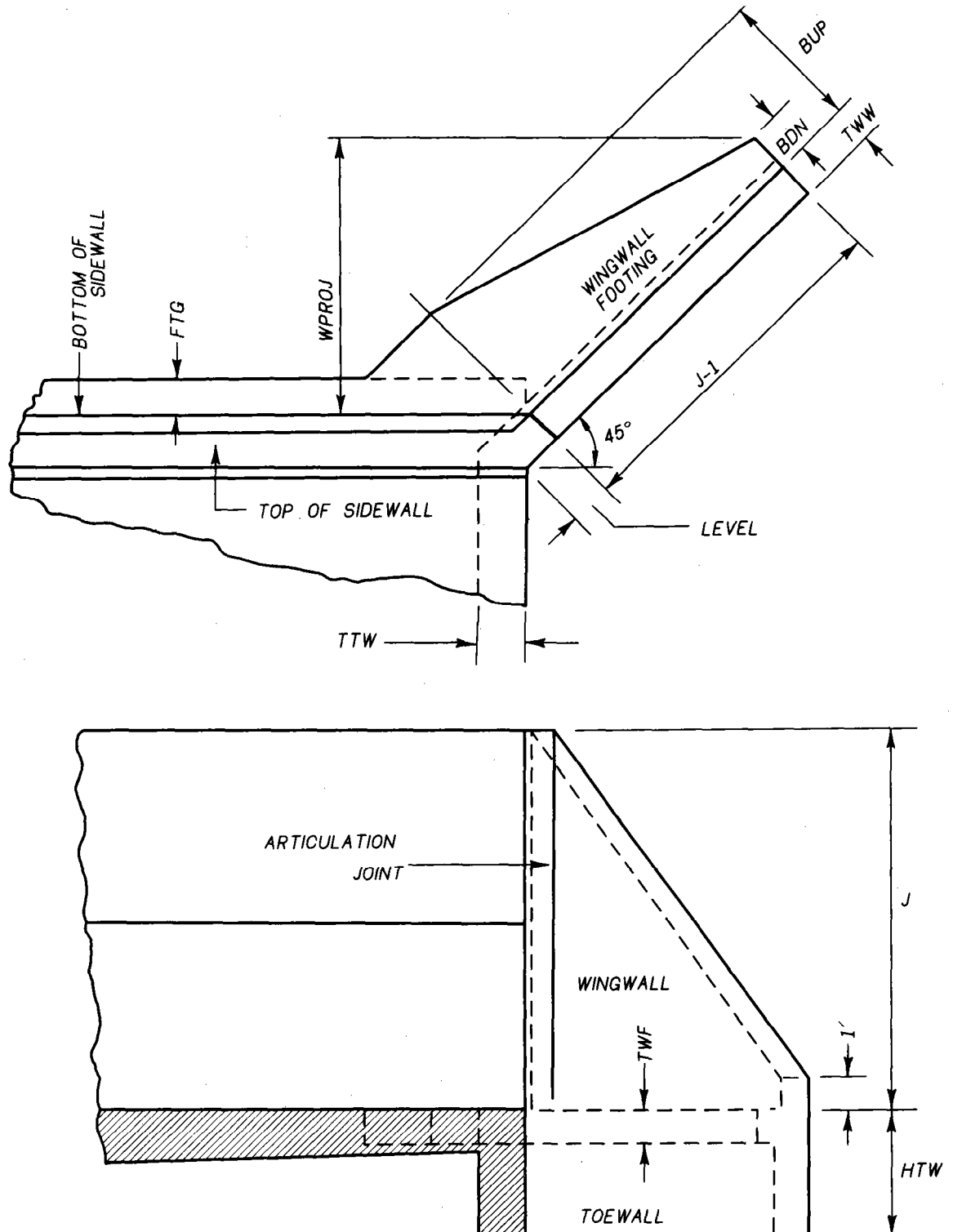
Figure 4. Wingwall layout

layout. The level distance locating the articulation joint varies depending on relative values of wingwall and sidewall thicknesses. This distance is discussed subsequently.

Loading Conditions

Two loading conditions are considered in the design of SAF stilling basins. Parameter values should be selected so that these loading conditions reflect extremes of probable conditions. The surface of the earthfill against the sidewall varies linearly from the top of the wall at the
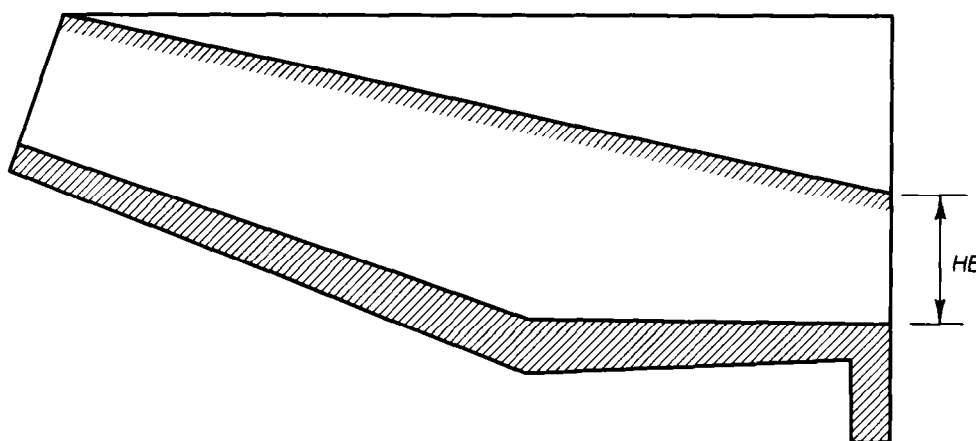
Figure 5. Variation of earthfill surface

upstream end to a height, HB, at the downstream end, see Figure 5.

Surcharge

Surcharge is not included herein as a specific loading. The effects of surcharge can be duplicated to some extent by arbitrarily increasing lateral pressure ratios, unit soil weights, or earthfill heights. Increasing the lateral pressure ratio, KO, is the preferred approach unless the surcharge is applied constantly.

Load Condition No. 1

This is the no flow loading, see Figure 6. It is meant to represent
conditions following a rapid lowering of the water surface in the basin
before the water table in the earthfill, and associated uplift, have
lowered significantly from some higher level. The tailwater depth in
the basin is HTW1. The uplift head above the top of the level floor slab
and footings is HUP1. This loading should maximize the difference be-
tween HUP1 and HTW1.

SECTION AA
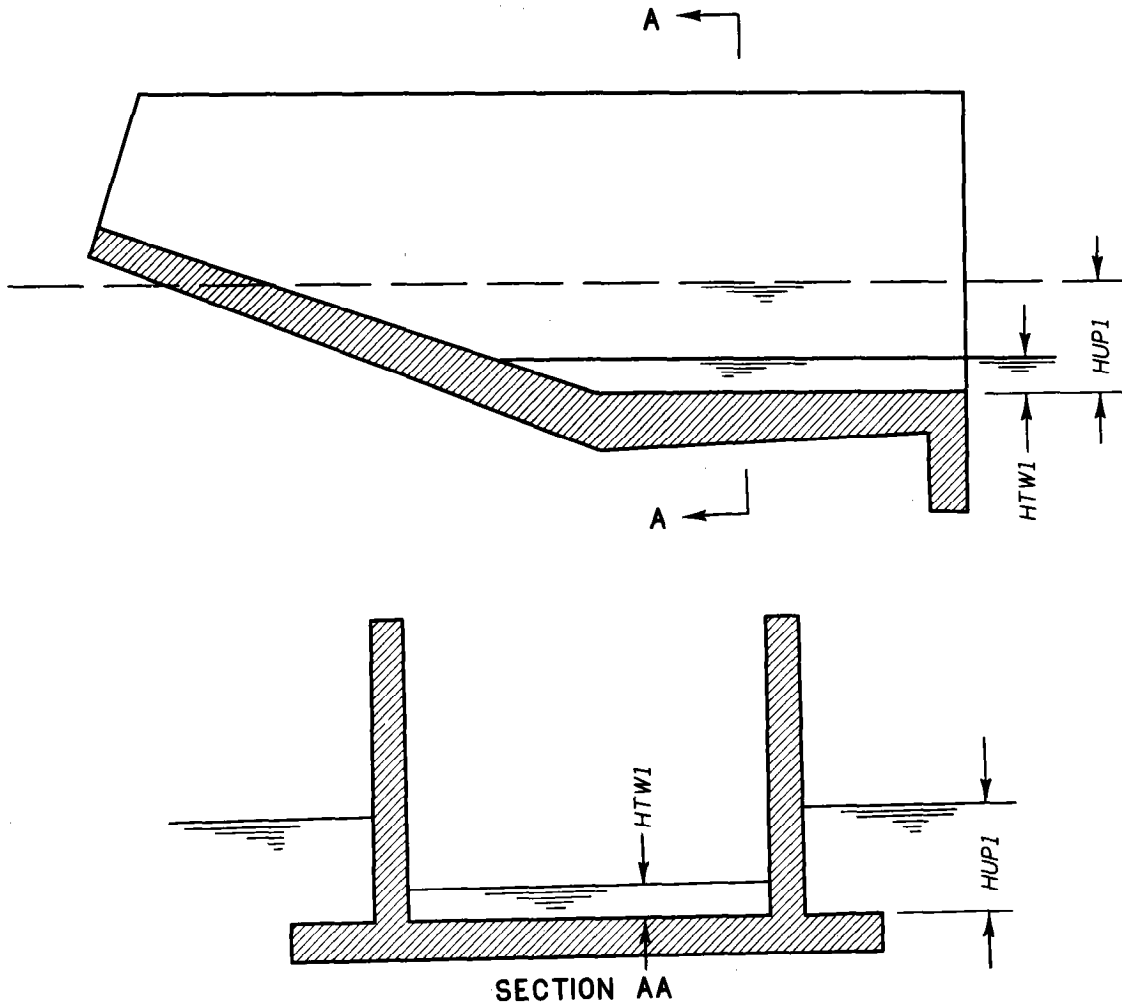
Figure 6. Load condition No. 1

Load Condition No. 2

This is the __full flow__ loading, see Figure 7. Flow enters the stilling basin at a depth, D1, and velocity, V1. These are the hydraulic parameters discussed in NEH-14 on pages 2.193 and following. Although it is admittedly a rough approximation, the water surface in the basin is assumed to vary linearly from the depth, D1, at the break-in-grade to the tailwater depth, HTW2, at the downstream end. The uplift head above the top of the level floor slab and footings is HUP2. Load condition No. 2 is meant to represent governing conditions when the basin is operating at full flow. Thus this loading should maximize both HTW2 and HUP2. The water surface on the outside of the basin walls is taken as HUP2 for all analyses except sidewall bending. Observe that the following relations must exist between the various water height parameters:

$$HTW2 \geq HUP2 \geq HUP1 \geq HTW1.$$

SECTION AA
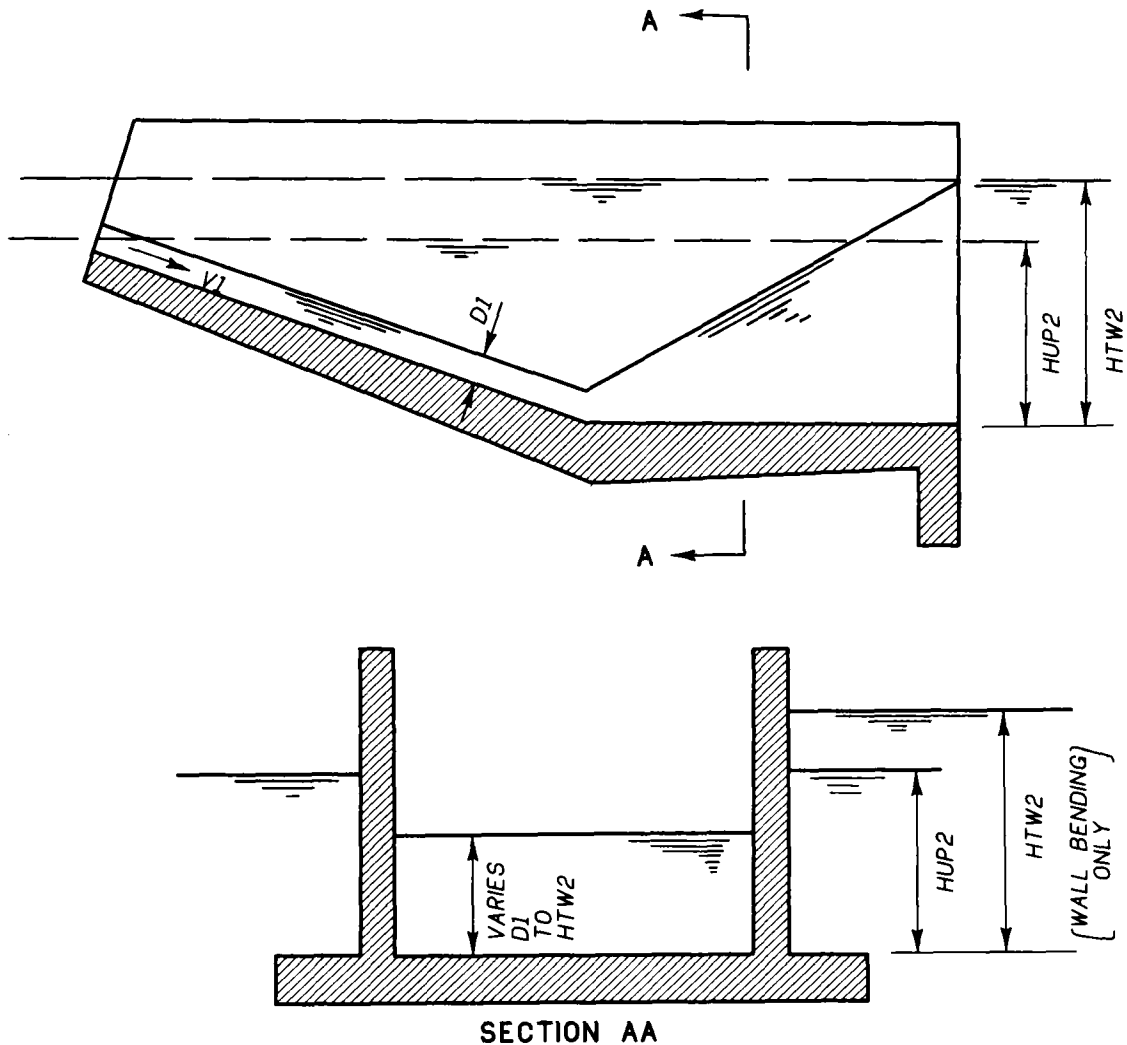
Figure 7. Load condition No. 2

Flotation Requirements

The total weight of the SAF stilling basin plus all downward forces acting on it must exceed the uplift forces by a suitable safety factor under all conditions of loading. Often the most critical case is load condition No. 2. However, with a sufficiently large difference between HUP1 and HTW1, load condition No. 1 will control. Hence both load conditions are investigated. The flotation safety factor, FLOATR, is selected by the user. Footing projections are provided, when required, to develop necessary additional downward forces.

Sliding Requirements

The horizontal resisting forces that can be mobilized must exceed the horizontal driving forces acting on the basin in a downstream direction by a suitable safety factor under all conditions of loading. Either load condition can control, hence both are investigated. The sliding safety factor, SLIDER, is selected by the user.

The forces resisting sliding are the frictional resistance between the basin and the foundation, the frictional resistance between the sidewalls and the earthfill, the passive resistance of the channel material downstream of the toewall, and certain hydrostatic pressures discussed below. The frictional force between basin and foundation is assumed to act along the bottom of the level floor slab. The frictional force between the sidewalls and earthfill is neglected as being extremely unreliable. The passive resistance of the channel material downstream of the toewall is neglected since it may be scoured away.

Sliding forces. The horizontal components of hydrostatic forces of concern in load condition No. 1 are shown in Figure 8. Both driving and resisting hydrostatic distributions are shown to cease at the elevation of the top of the floor of the basin. While this is of course untrue, these pressures must reach equilibrium through drains or other seepage,
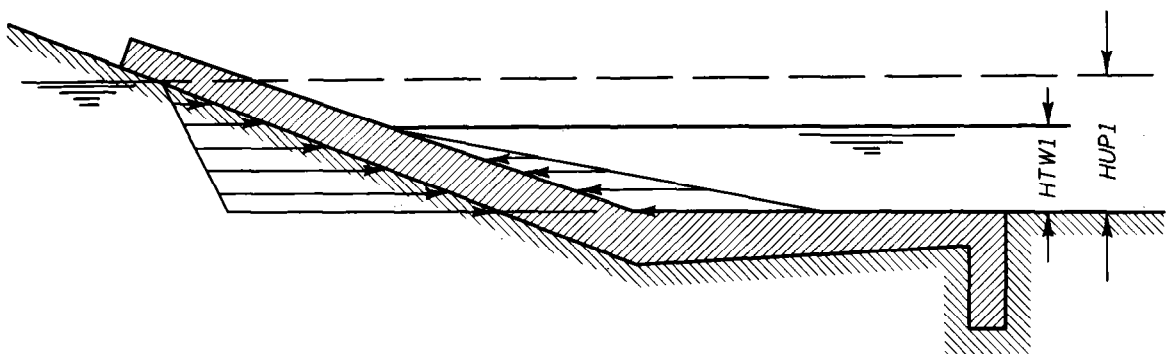
Figure 8. Horizontal components of hydrostatic
forces, load condition No. 1

and will essentially cancel each other below that elevation.

In load condition No. 2, the horizontal force acting on the basin, due to the water in the basin, is shown in Figure 9 as FM. The force, FM, is due to the change in momentum, in a horizontal direction, of the water on the level floor slab of the basin.
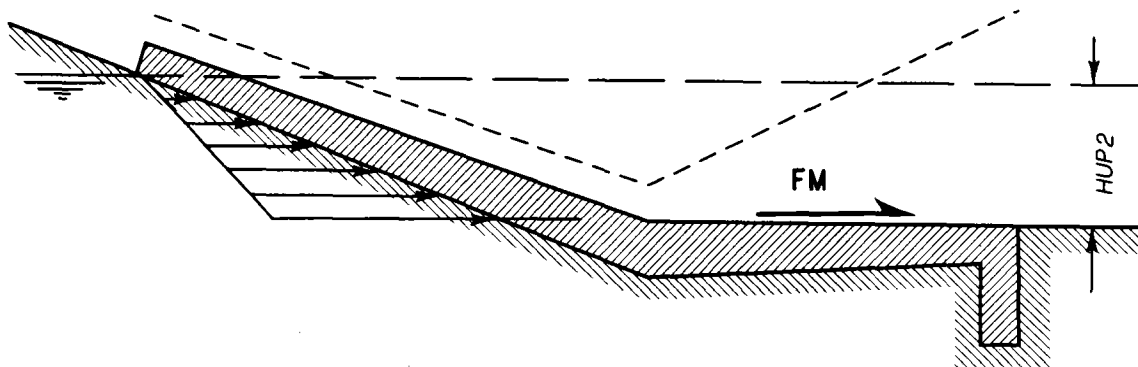
Figure 9. Sliding forces, load condition No. 2

Momentum considerations. Figure 10 shows two tailwater conditions with the force FM shown as the horizontal force acting on the water due to
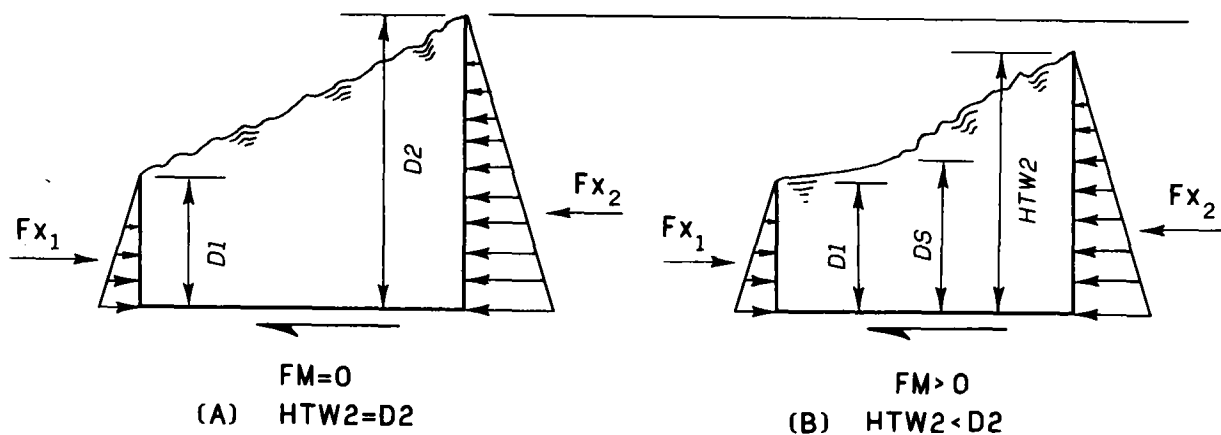
Figure 10. Momentum relations in basin

the basin. In sketch (A) the tailwater is D2, the sequent depth to depth, D1. In sketch (B) the tailwater is HTW2 which is shown as less than D2. From momentum principles, letting V1, D1, and V2, HTW2 be velocity and depth of flow at beginning and end sections respectively,

$$F_{x_1} - F_{x_2} - FM = \frac{\gamma}{g} Q(V2 - V1)$$

or

$$FM = (F_{x_1} + \frac{\gamma}{g} QV1) - (F_{x_2} + \frac{\gamma}{g} QV2)$$

for rectangular channels, and in terms of per foot of width

$$FM = (\frac{\gamma D1^2}{2} + \frac{\gamma}{g} q\, V1) - (\frac{\gamma \overline{HTW2}^2}{2} + \frac{\gamma}{g} q\, V2)$$

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which by substitution can be written

$$FM = FM1 - FM2$$

where, with depths in ft, velocities in fps

> FM ≡ net force due to horizontal change in momentum, lbs per ft width of channel
>
> $FM1$ ≡ momentum force at section of depth, D1, $= (\dfrac{\gamma D1^2}{2} + \dfrac{\gamma}{g} q\, V1)$, lbs per ft width of channel
>
> $FM2$ ≡ momentum force at section of depth, HTW2, $= (\dfrac{\gamma \overline{HTW2}^2}{2} + \dfrac{\gamma}{g} q\, V2)$, lbs per ft of width of channel
>
> γ = 62.4 lbs per cu ft
>
> g = 32.2 ft per sec^2
>
> q = discharge, cfs per ft width of channel
>
> $V2$ = V1 x D1/HTW2

Taking FM = 0 defines the case of a hydraulic jump. The beginning and end depths are sequent depths, the end depth is given by

$$D2 = \tfrac{1}{2} D1\left(\sqrt{8F_1 + 1} \ -1\right)$$

where

$$F_1 = \text{Froude's number} = V1^2/gD1$$

When the tailwater is less than D2, as in sketch (B), FM2 is less than FM1, that is, FM > 0. Hence the force, FM, acting on the basin tends to push the basin downstream. The depth, DS, is the sequent depth to the depth, HTW2. The water surface profile is roughly that shown.

When the tailwater is more than D2, sketch not shown, FM2 is more than FM1, that is FM < 0. Hence the force, FM, acting on the basin tends to push the basin upstream. The jump tends to move upstream since somewhere between the depth, D1, and tailwater depth there is a depth, DS, that is sequent to D1.

However, the sum of FM and the horizontal component of the hydrostatic force due to HUP2, see Figure 9, is of more concern than consideration of the variation of FM alone. Let FH2 be the hydrostatic force and FS2 be the sum force, then in lbs per ft width of channel

$$FS2 = FH2 + FM.$$

For purposes of study, take the particular case of HUP2 = HTW2, then

$$FS2 = \frac{\gamma \overline{HTW2}^2}{2} + FM1 - \left(\frac{\gamma \overline{HTW2}^2}{2} + \frac{\gamma}{g}\frac{q^2}{HTW2}\right)$$

or

$$FS2 = FM1 - \frac{\gamma}{g}\frac{q^2}{HTW2}$$

differentiating with respect to HTW2 to find the value of HTW2 making

FS2 a maximum gives
$$HTW2 = \infty.$$

Thus FS2 approaches FM1 as HTW2 approaches ∞. The height of the side-walls, J is the control, so that FS2 maximum would occur when HTW2 = HUP2 = J.

In design, the condition resulting in the minimum actual factor of safety against sliding should be checked. This condition probably occurs when HTW2 = D2. For higher tailwaters than D2, the basin becomes essentially full of water so that an increase in FS2 is offset by an increase in frictional resistance due to increased water weight.

Possible modification of load condition No. 2. As explained in the next section, HTW2 and HUP2 are selected by the user. If HUP2 and/or HTW2 are selected greater than the sequent depth, D2, they are reduced during design to D2. This is done for the reasons discussed immediately above, namely, HTW2 = D2 represents a more critical situation than when HUP2 and/or HTW2 are more than D2.

Design Parameters

There are some twenty-two independent parameters involved in the struc-tural design of the aforementioned three types of SAF stilling basins. These parameters are classified as either primary parameters or secondary parameters. Values for primary parameters must be supplied by the user for each design run. Secondary parameters will be assigned default values if values are not supplied by the user. The methods of supplying para-meter values are discussed under the section, "Computer Designs."

Primary Parameters

W ≡ width of SAF stilling basin, in ft

J ≡ height of basin sidewalls, in ft

LB ≡ length of basin, in ft

N ≡ height of sidewalls at upstream end section, in ft

D1 ≡ entrance depth of water to SAF stilling basin, in ft

V1 ≡ entrance velocity of water to SAF stilling basin, in fps

Secondary Parameters

The secondary parameters and their default values are listed in Table 1. The user should make an effort to evaluate the secondary parameter values he wishes to use. Use of default values may result in an overly conserva-tive (or unconservative) design. Usage of the various parameters is ex-plained where first encountered. The default value for HTW2 is a func-tion of D2, the sequent depth to depth D1. The value of Froude's number is computed and it, and D2 are output with the parameter values selected for the design run.

Table 1. Secondary parameters and default values

Parameter	Default Value
HTW2 ≡ tailwater depth above top of floor of basin for load condition No. 2, in ft	D2
HUP2 ≡ uplift head above top of floor of basin for load condition No. 2, in ft	HTW2
HTW1 ≡ tailwater depth above top of floor of basin for load condition No. 1, in ft	0
HUP1 ≡ uplift head above top of floor of basin for load condition No. 1, in ft	0.5 HUP2
HB ≡ earthfill height above top of floor of basin at downstream end of basin, in ft	0.5J
ZS ≡ slope parameter of inclined portion of stilling basin	3.0
HTW ≡ depth of toewall below top of floor of basin, in ft	4.0
TTW ≡ thickness of toewall, in inches	10.0
GM ≡ moist unit weight of earthfill, in pcf	120.
GS ≡ saturated unit weight of earthfill, in pcf	140.
KO ≡ lateral earth pressure ratio	0.8
BAT ≡ inside sidewall batter, in inches per ft of height	0.375
MAXFTG ≡ maximum acceptable footing projection, in ft	0.5W
FLOATR ≡ safety factor against flotation	1.5
SLIDER ≡ safety factor against sliding	1.0
CFSC ≡ coefficient of friction, soil to concrete	0.35

Design Criteria

Materials

Class 4000 concrete and intermediate grade steel are assumed.

Working Stress Design

Design of sections is in accordance with working stress methods. The allowable stresses in psi are

Extreme fiber stress in flexure	$f_c = 1600$
Shear, V/bD*	$v = 70$
Flexural Bond	
tension top bars	$u = 3.4\sqrt{f_c'}/D$
other tension bars	$u = 4.8\sqrt{f_c'}/D$
Steel	
in tension	$f_s = 20,000$
in compression, axially loaded	$f_s = 16,000$

Minimum Slab Thicknesses

Walls	10 inches
Bottom slabs	11 inches

Temperature and Shrinkage Steel

The minimum steel ratios are

for unexposed faces	$p_t = 0.001$
for exposed faces	$p_t = 0.002$

Slabs more than 32 inches thick are taken as 32 inches.

Web Reinforcement

The necessity of providing some type of stirrup or tie in the slab because of bending action is avoided by

(1) limiting the shear stress, as a measure of diagonal tension, so that web steel is not required, and

(2) providing sufficient effective depth of sections so that compression steel is not required for bending.

Cover for Reinforcement

Steel cover is everywhere 2 inches except for outside steel in bottom slabs where cover is 3 inches.

*Shear sometimes critical at D from face, sometimes at face, see page 17 of TR-42.

Steel Required by Combined Bending Moment and Direct Force

Required area determined as explained on pages 31 - 34 of TR-42, "Single Cell Rectangular Conduits - Criteria and Procedures for Structural Design."

Spacing Required by Flexural Bond

Spacing determined as explained on page 47 of TR-42.

Spacing of Reinforcement

The maximum permissible spacing of any reinforcement is 18 inches.

Preliminary Designs

Trial concrete thicknesses are determined for various critical dimensions, and preliminary concrete volumes are computed, during the preliminary design phase of the structural design of SAF stilling basins. These quantities may be increased during detail design if computations for required steel areas indicate thicknesses are inadequate. Assumptions, criteria, and procedures for the several basin types are discussed below. Transverse strength of the toewall is neglected throughout these computations. Topics applicable to more than one basin type are presented most fully when first encountered.

Type (A)

Preliminary design of type (A) basins proceeds in an orderly manner. First, sidewall geometry, and load variables, are established. Next, required sidewall thicknesses for wall bending are determined. Next, the basin is checked for flotation. Footing projections, FTG, are provided if required. Then, bearing pressures are checked to insure positive pressures within allowable values. Then, floor slab thicknesses are checked for shear and transverse bending. Finally, the basin is checked for sliding. At any stage of design after sidewall thicknesses are determined, thicknesses or footing projections are incremented if found inadequate and the design is recycled accordingly.

Sidewall geometry and load variables. Sidewall dimensions and thicknesses are shown in Figure 11. The inside face of the sidewall is vertical from the top of the sidewall down a distance, HV. This distance is the larger of $J/2$ or HN. Below the distance, HV, the sidewall is battered for ice protection at the rate of BAT inches per foot. BAT may be set equal to zero if desired. The outside face of the sidewall is a plane surface.

The slope hypotenuse parameter, ZH, is

$$ZH = \sqrt{1 + ZS^2}$$

Thus, with all distances in feet

LN   = N/ZH

HN   = LN x ZS

HS   = J - HN

LS   = HS x ZS

LBOT = LS + LB

LTOP = LBOT - LN

If LTOP is less than LB, that is, N is too big, a message is given and the design is canceled.
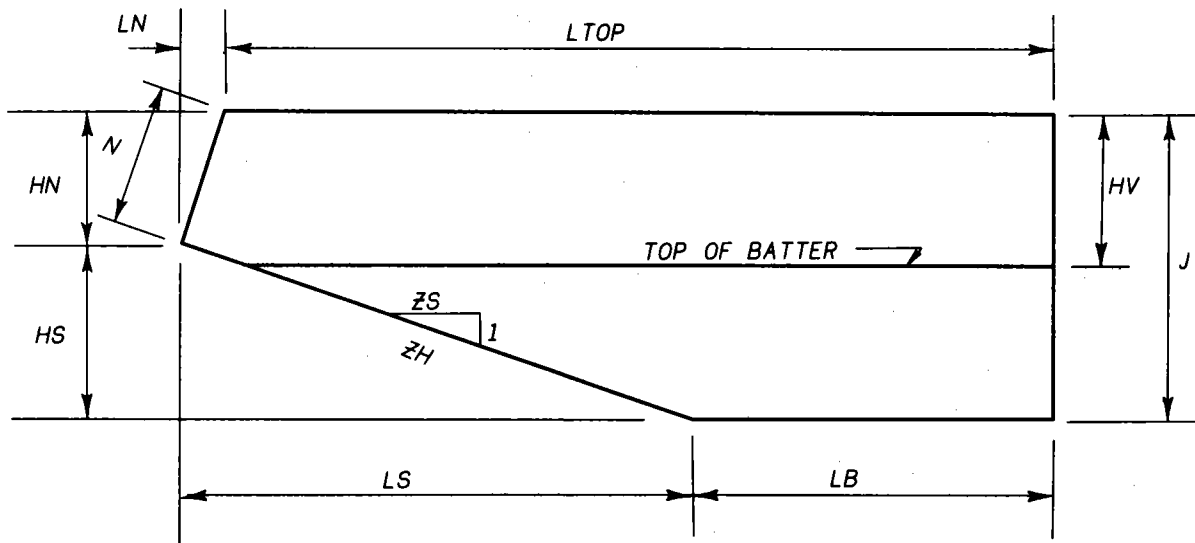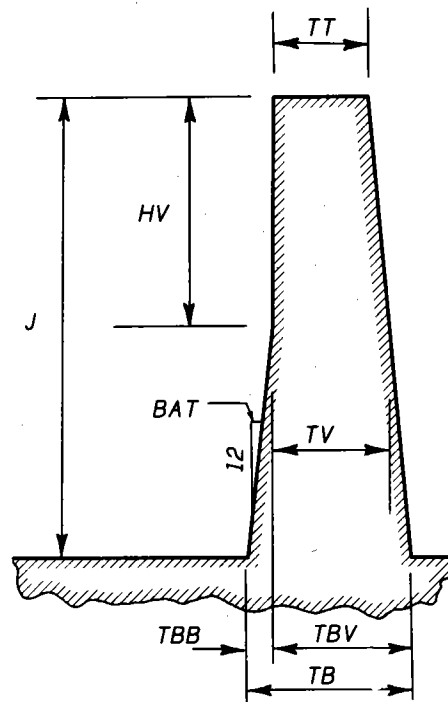
Figure 11. Sidewall dimensions and thicknesses

It is later shown that sidewall thicknesses may be controlled at any of
the three sections shown in Figure 12. Hence it is desirable to pre-
establish various section heights, earthfill heights, tailwater depths,
and uplift heads.

Section 2 is midway between sections 1 and 3, hence for section heights, in feet

$$HS1 = N \times ZH/ZS$$

$$HS3 = J$$

$$HS2 = 0.5(HS1 + HS3)$$

similarly for earthfill heights, in feet

$$HB1 = HS1$$

$$HB3 = HB + (J - HB) \times LB/LTOP$$

$$HB2 = 0.5 (HB1 + HB3)$$
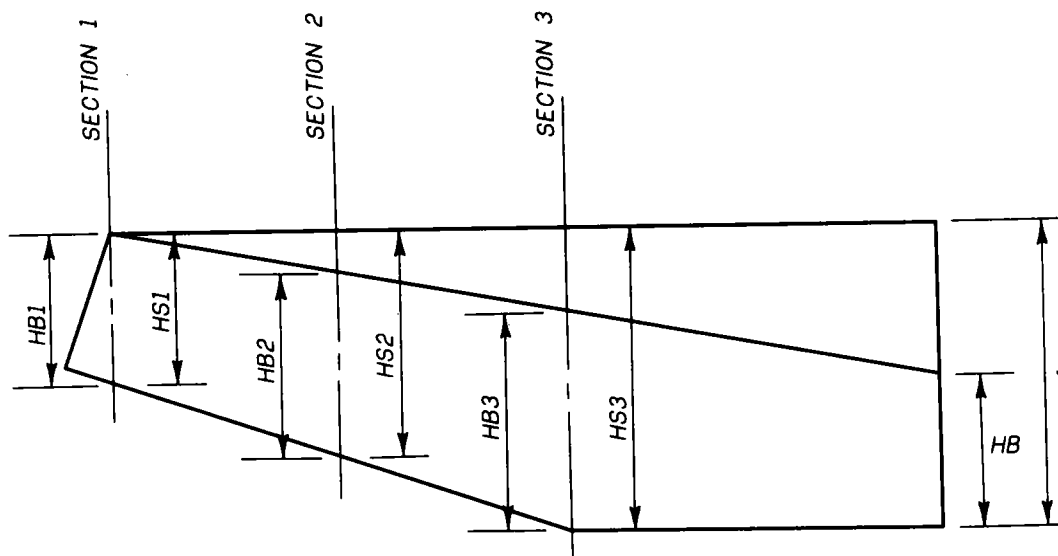
Figure 12. Section and earthfill heights

Tailwater depths, in feet, on the various sections can be obtained from Figure 13 for load condition No. 2 as

$$HT21 = HS1 - (J - HTW2)$$

$$HT23 = HTW2$$

$$HT22 = 0.5(HT21 + HT23)$$

if $HT21 < 0$ set $HT21 = 0$

if $HT22 < 0$ set $HT22 = 0$

Tailwater depths for load condition No. 1, HT11, HT13, and HT12 can be determined similarly, likewise for uplift heads HU21, HU23, HU22, and HU11, HU13, HU12.

20
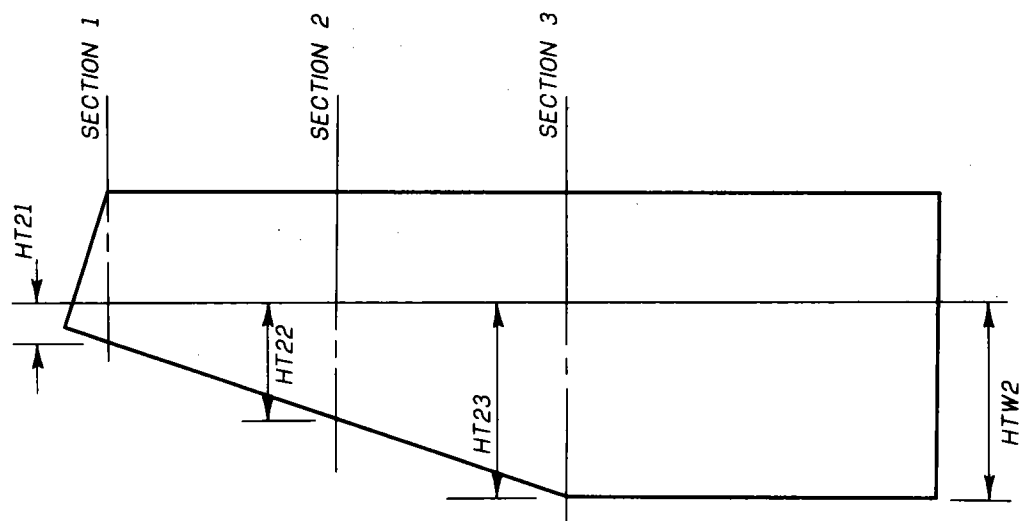
Figure 13. Tailwater depths for load condition No. 2

Sidewall bending. The sidewall is analyzed as a series of cantilever beams of unit width. The thickness at the top of the wall, TT, is set at 10 inches. Either load condition No. 1 (LC #1) or load condition No. 2 (LC #2) can control wall thickness requirements. Because (1) both shear and moment increase exponentially with depth, and (2) HB may range

(A) LC #1   (B) LC #2
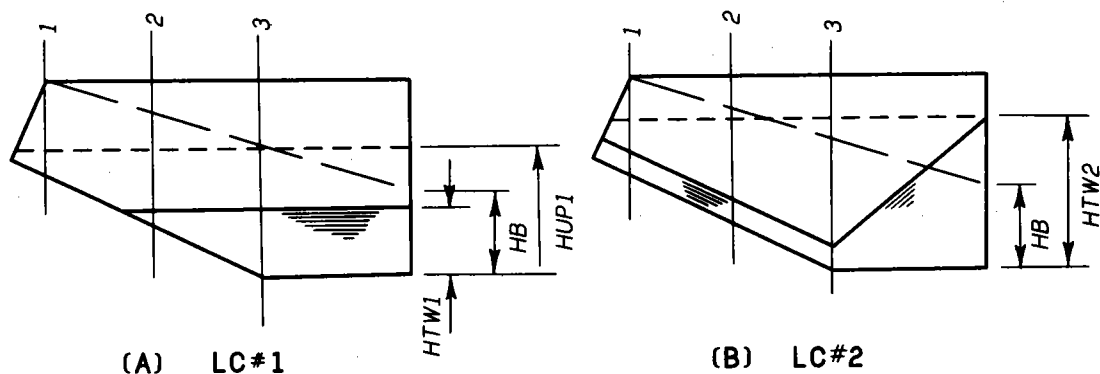
Figure 14. Considerations for sidewall bending, type (A) basin

from zero up to J, the following is true. The thickness required at the bottom of any section may be governed by the thickness required by flexure at the bottom of that section or by the thickness required at the bottom of either of the other two sections. Therefore the first step in designing the sidewall is to obtain the thicknesses required at the bottoms of sections 1, 2, and 3.

The thickness at the bottom of the wall at any section is selected as the largest thickness required by: shear for LC #1, moment and direct force for LC #1, shear for LC #2, or moment and direct force for LC #2. Illustrative computations for a section of height, HSW, and a possible loading case follow. See Figure 15 for definition of symbols.

(A) WORKING LOADINGS   (B) HV>HSW   (C) HV<HSW
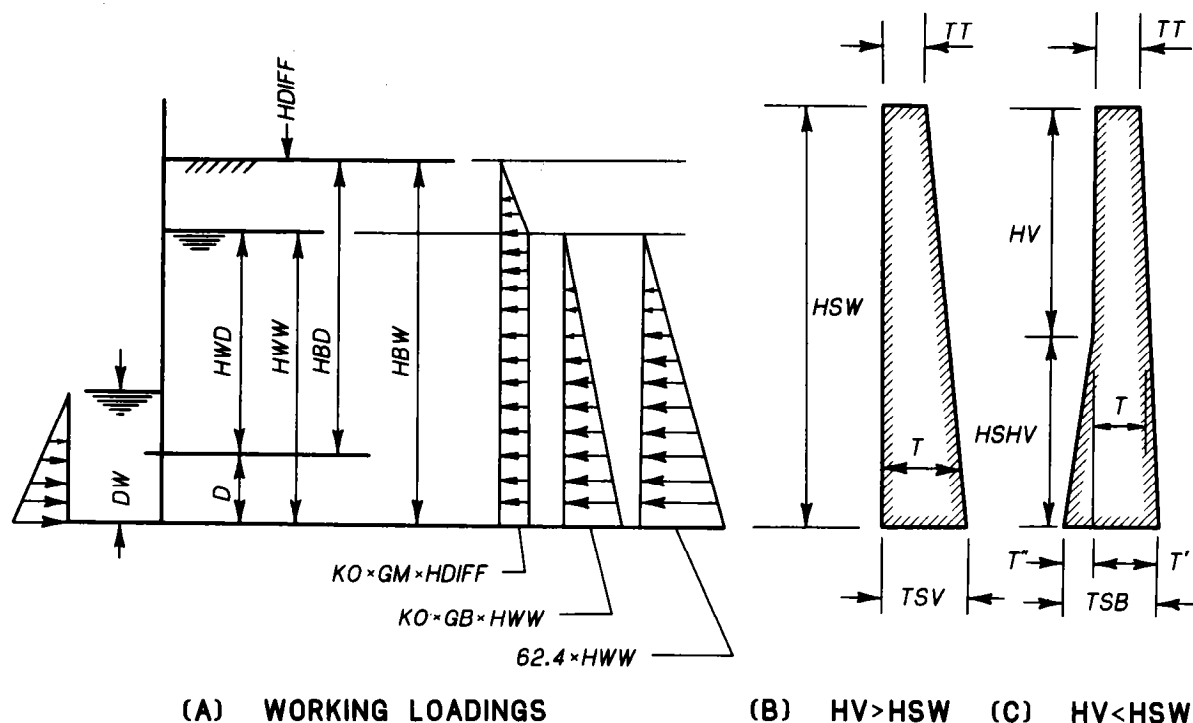
Figure 15. Thickness at bottom of section when HBW > HWW

The working values HSW, HBW, HWW, and DW are obtained from HSn, HBn, HUln or HT2n, and HT1n or Dl values as appropriate to the section under investigation.

Let HDIFF = HBW - HWW

For any effective depth, D, in inches

$$HBD = HBW - D/12$$

$$HWD = HWW - D/12$$

$$DWD = DW - D/12$$

Then the shear, in lbs per ft, at D from the face for the case shown is:

$$V = 31.2 \times (HWD^2 - DWD^2) + KO \times GM \times HDIFF \times (0.5 \times HDIFF + HWD)$$

$$+ 0.5 \times KO \times GB \times HWD^2$$

where GB = GS - 62.4 is the buoyant weight of the earthfill, in pcf

so

$$D = \frac{V}{vb} = \frac{V}{70 \times 12} = \frac{V}{840}$$

An iterative process is required since the assumed D must agree with the computed required D. When the correct value of D is obtained, the thickness, T, at D from the face is

$$T = D + 2.5$$

and the thickness at the bottom is

$$TSV = 10 + (T - 10) \times HSW/(HSW - D/12).$$

If, for the section under investigation, HV > HSW, the thickness required at the bottom of the section by shear is TSV. However, if HV < HSW, the thickness required at the bottom of the section may be controlled by the thickness required by shear at HV from the top of the section, see sketches (B) and (C) of Figure 15.

Thus if HV < HSW, compute the shear, V, at HV from the top by computations similar to those above. Then

$$D = \frac{V}{840}$$

and

$$T = D + 2.5 \text{ at HV from the top.}$$

So

$$T' = 10 + (T - 10) \times HSW/HV$$

$$T'' = HSHV \times BAT$$

and

$$TSB = T' + T''.$$

The thickness required at the bottom of the section by shear is the larger of TSV or TSB.

The bending moment at the bottom of the sidewall, in ft lbs per ft, for the case shown is

$$M = 10.4 \times (HWW^3 - DW^3) + 0.5 \times KO \times GM \times HDIFF^2 \times (HDIFF/3 + HWW)$$
$$+ 0.5 \times KO \times GM \times HDIFF \times HWW^2$$
$$+ 0.5 \times KO \times GB \times HWW^3/3.$$

The direct compressive force due to the sidewall, in lbs per ft, for a bottom thickness, TSV, is

$$N = 6.25 \times HSW \times (TT + TSV)$$

The equivalent moment, M_s, is

$$M_s = M + N \times (0.5 \times TSV - 2.5)/12$$

So the required thickness at the bottom for balanced working stresses is

$$TSV = (0.003683 \times M_s)^{1/2} + 2.5$$

An iterative process is again required since the assumed TSV must agree with the computed required TSV.

Again, if HV > HSW, then TSV is the thickness required at the bottom of the section by moment. If HV < HSW, compute the moment and direct

force at HV from the top and get T and HV from the top by computations similar to those above.
Then

$$T' = 10 + (T - 10) \times HSW/HV$$

so

$$TSB = T' + T''$$

and the thickness required at the bottom of the section by moment is the larger of TSV or TSB.

The thickness required at the bottom of the section under investigation for the load condition under investigation is the larger of those obtained from the foregoing computations for shear and moment. Then the thickness required at the bottom of a particular section is the larger of those obtained from LC #1 and LC #2. Let these bottom thicknesses be TAB1, TAB2, and TAB3 as indicated in Figure 16, then for the case shown

$$TV1 = TT + (TAB1 - TT) \times HV/HS1$$

$$TV2 = TT + (TAB2 - TT - (HS2 - HV) \times BAT) \times HV/HS2$$

$$TV3 = TT + (TAB3 - TT - (HS3 - HV) \times BAT) \times HV/HS3$$

so that TV in Figure 11 is the largest of TV1, TV2, or TV3. With TV known, TBV is rounded up to the next integer value from

$$TBV = TT + (TV - TT) \times J/HV$$

and TBB is rounded to the nearest integer value from

$$TBB = (J - HV) \times BAT$$

so

$$TB = TBB + TBV$$

Thus the sidewall thicknesses are completely defined.
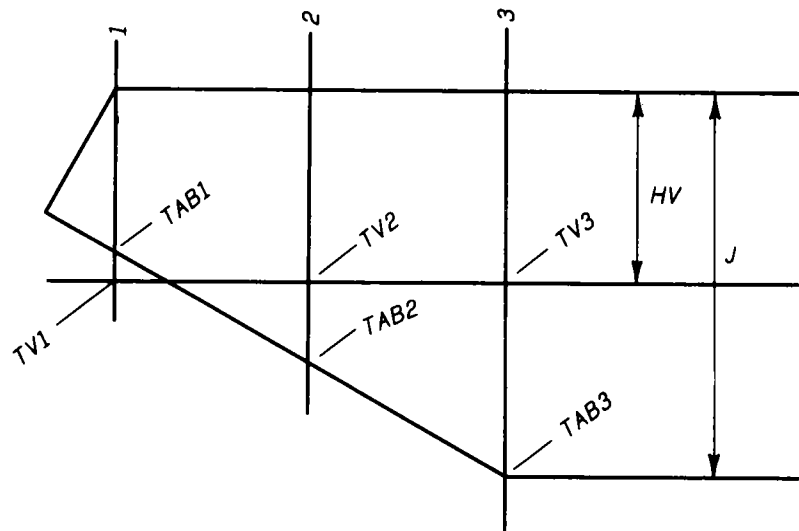
Figure 16. Determination of controlling thickness

Flotation. As previously noted, either LC #1 or LC #2 can be critical with regard to flotation. Figures 17 through 20 indicate the various
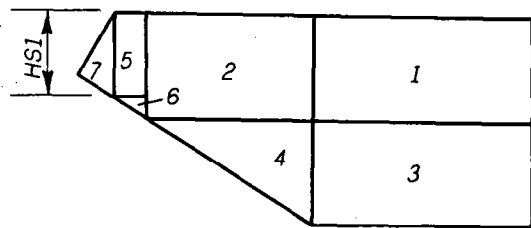
(A) HS1<HV
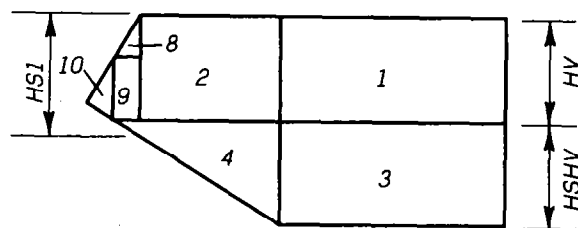
(B) HS1>HV
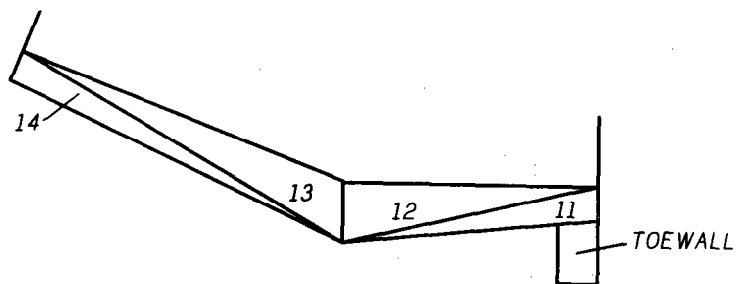
(C) FLOOR SLAB

Figure 17. Components of sidewall and slab volumes

LC#2

(A) HTW2>HSHV
D1<HSHV

(B) HTW2<HSHV
D1<HSHV

(C) HTW2>HSHV
D1>HSHV

LC#1

(D) HTW1<HSHV

(E) HTW1>HSHV
HTW1<HS

(F) HTW1>HS
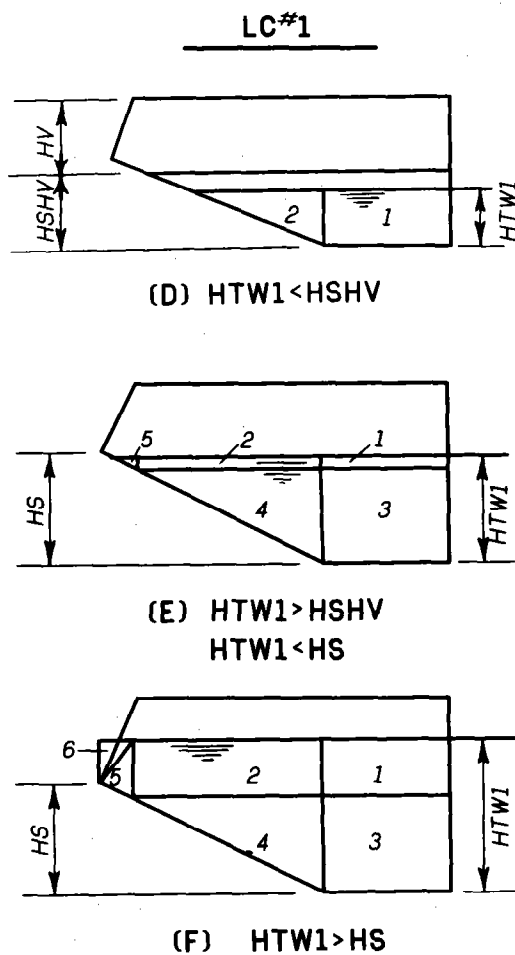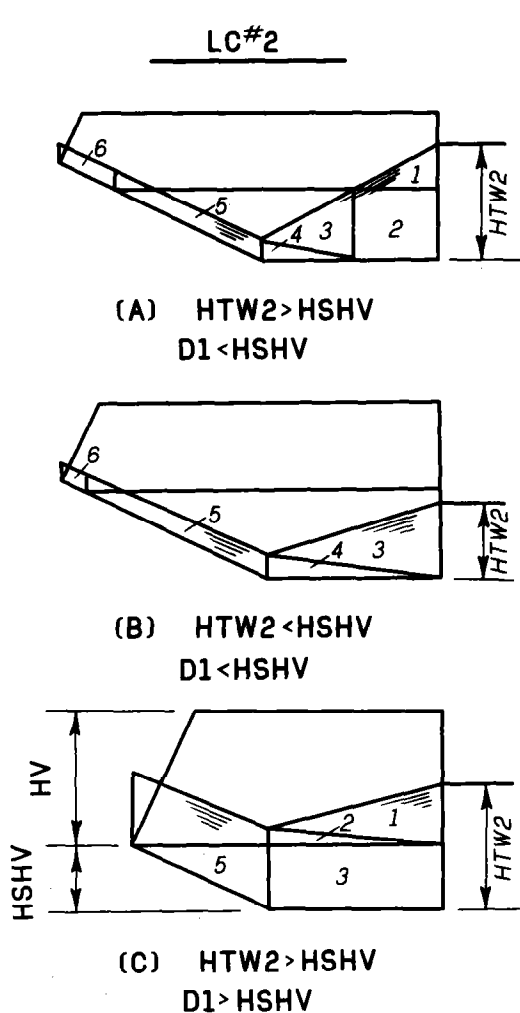
Figure 18. Components of volume of water in basin

components of weight and uplift that must be obtained to check flotation requirements. The magnitudes of these components are maintained for subsequent analyses. Figure 17 shows how the sidewalls are partitioned into components depending on relative values of HS1 and HV. Figure 18 shows the partitioning of the water volumes in the basin depending on relative values of tailwater and basin dimensions. Figure 19 shows the variation of footing pressures along the stilling basin and how the loads on a footing are partitioned. Footing pressures, PFn, are computed for both load conditions. The water pressures on any footing are a function of the corresponding head HUP1 or HUP2, this being consistent with the assumption that uplift is a function of HUP1 or HUP2. Figure 20 shows the partitioning of uplift components depending on relative values of the corresponding head HUP1 or HUP2 and basin dimensions.
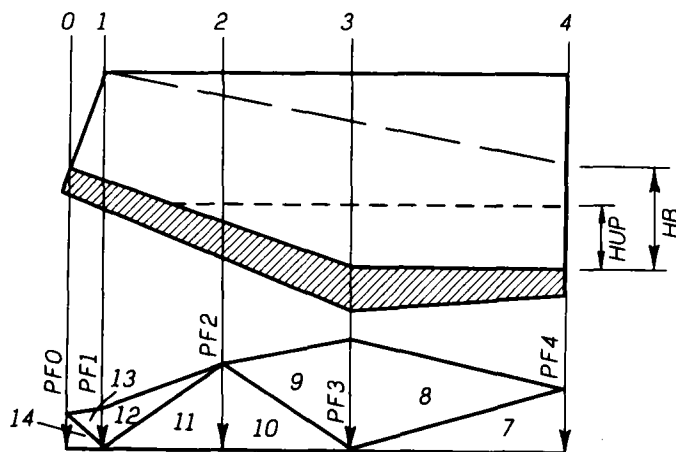
Figure 19. Footing pressures and load components for LC#1 or LC#2

$$\text{(A) } HUP > (HS - \frac{TSUP}{12} \cdot \frac{ZS}{ZH})$$

$$\text{(B) } HUP < (HS - \frac{TSUP}{12} \cdot \frac{ZS}{ZH})$$
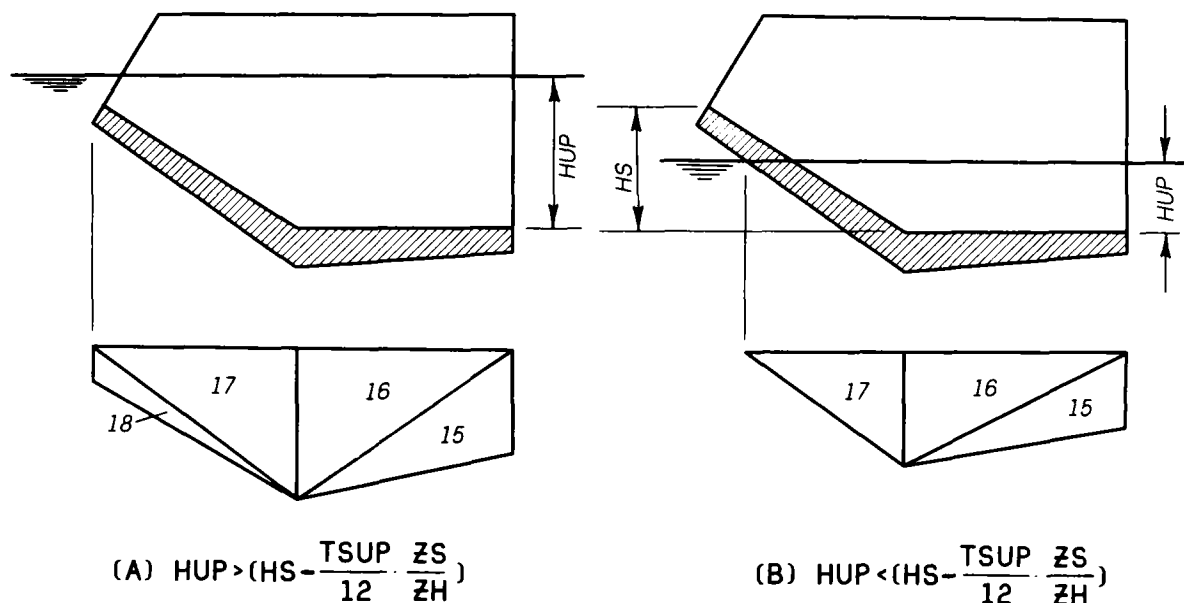
Figure 20. Components of uplift for LC#1 or LC#2

The toewall of Figure 17 is taken at the buoyant weight of concrete to compensate for its lack of consideration in Figure 20.

For each load condition, the sum of all downward forces, SDOWN, and the sum of the uplift forces, SUP, must satisfy the relation

$$\frac{SDOWN}{SUP} \geqq FLOATR$$

The initial values of floor slab thicknesses and footing projections are

$$TSUP = TT + (TBV - TT) \times HN/J + 1$$

rounded up to the next integer value, and

$$TSBG = TB + 1.$$

$$TSDN = TB + 1.$$

$$FTG = 0.$$

If the flotation requirement is not satisfied, FTG is set at 1.0. If again flotation is unsatisfied, a series of attempts is begun in which the footing projections and floor slab thicknesses are variously incremented until FTG = MAXFTG and TSBG = TB + 10. If the flotation criteria is still unsatisfied, the design is abandoned, and a cancellation message is given.

Bearing pressures. The distribution of bearing (contact) pressures over the base of the basin depends on the rigidity of the structure, the foundation material characteristics, and the magnitude and location of the resultant vertical force acting on the structure. The pressure distribution is three-dimensional and highly indeterminate. For this reason, no attempt is made herein to apply an elastic analysis to determine bearing pressures such as is done for floor slab bearing in TR-50. In accordance with common practice, the assumption is made that bearing pressures vary linearly along any section parallel to the longitudinal centerline of the outlet, and that these pressures are constant along any section at right angles to the centerline.

The maximum allowable bearing pressure, in psf, is taken as the smaller of

$$PALLOW = 2000 + GB \times (HB1 + TSUP/12)$$

or

$$PALLOW = 2000 + GB \times (HB + TSDN/12).$$

Either load condition can control. Bearing pressures over the base must be everywhere compressive and within allowable values.

A possible case of LC #2 is used for illustration, see Figure 21. In the sketch, note that the force due to change in momentum, FM, in lbs per ft of width is multiplied by W to obtain the total force. The force, FH2 due to HUP2, in lbs per ft of width, is also multiplied by W to obtain the net hydrostatic driving force. This is done in lieu of multiplying FH2 by the overall width of the basin and then subtracting out the resisting forces acting on the footing projections, etc. If

$$HUP2 > (HS - \frac{TSUP}{12} \cdot \frac{ZS}{ZH}),$$

see Figure 20, it is assumed that the upper part of FH2 bears on the stilling basin through the upstream channel section. The resultant of the vertical forces including uplift, VNET, is located by taking moments about the indicated moment center of the horizontal forces and the vertical forces
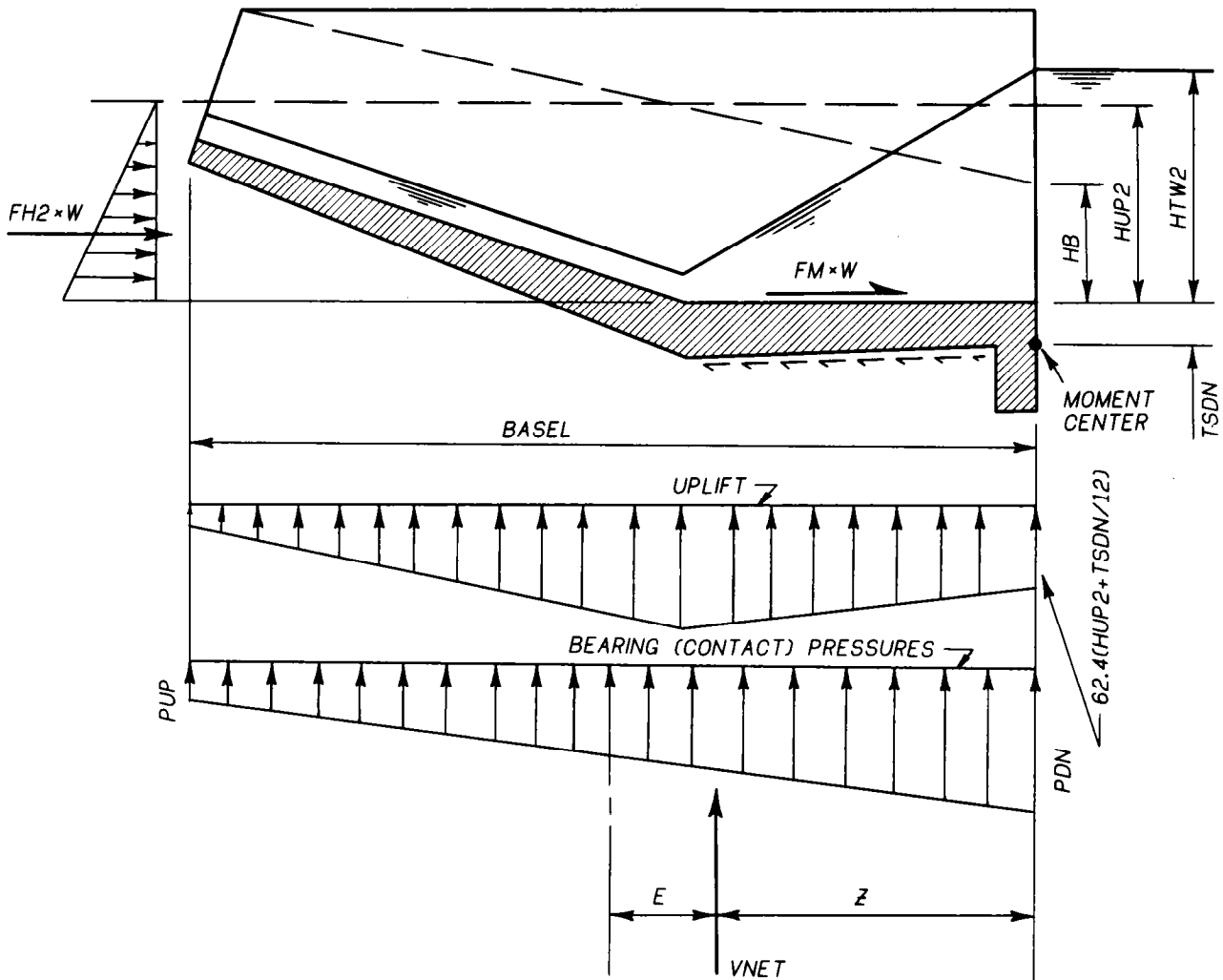
Figure 21. Determination of bearing pressures for LC#2

previously computed in the flotation analyses. Thus, in lbs

VNET = SDOWN - SUP

and, in ft

BASEL = LBOT + TSUP/(12 x ZH)

WO   = W + 2(TBV/12 + FTG)

Z   = M/VNET

E   = BASEL/2 - Z

where M is the resultant moment about the moment center in ft lbs. Then, in psf

PAVER = VNET/(BASEL x WO)

PDN   = PAVER(1 + 6E/BASEL)

PUP   = PAVER(1 - 6E/BASEL).

If either PUP or PDN is negative, an attempt is made to increase the loading on the structure. This is done by incrementing FTG and also TSBG together with the corresponding TSUP or TSDN. If either PUP or PDN exceeds the allowable bearing value, FTG is incremented in an attempt to spread the load. These attempts are continued up to FTG = MAXFTG.

Floor slab shear. Shear will sometimes govern required floor slab thickness. Three cross sections are checked: the downstream end section, the section at the break-in-grade, and the upstream end section. Both load conditions are investigated. For any section and load condition, the shear stress at D from the face of the sidewall is obtained as follows, see Figure 22. Let the net uniform loading between sidewalls be PNET, in psf per ft, then

$$PNET = PB + PUW - PTS - PDW$$

and the required thickness, in inches, is

$$TSR = |PNET| \times 0.5 \times W/(840 + |PNET|/12) + 3.5$$

where, with respect to the section and load condition under investigation

PB ≡ bearing pressure, psf

PUW ≡ uplift pressure = 62.4(HUW + TS/12), psf

HUW ≡ uplift head above top of slab, ft

TS ≡ slab thickness, inches

PTS ≡ dead weight of slab = 12.5 × TS, psf

PDW ≡ water pressure in basin = 62.4 × DW, psf

DW ≡ depth of water in basin, ft.

If the required thickness is greater than the actual thickness at the section, the design is recycled starting at the flotation investigations using the increased thickness and other current slab thicknesses as initial values.

Floor slab bending. Transverse bending moment at the center of the floor slab will sometimes govern required floor slab thicknesses. The downstream end section, the break-in-grade section, and the upstream end section are checked for both load conditions. Note that in general, the sum of the vertical forces acting on any section under investigation will not equal zero unless longitudinal shearing forces on each side of the section are taken in account. The distribution of these shearing forces is unknown. They are therefore treated in two ways to determine their maximum probable effect. As shown by Figure 22, they are taken as longitudinal shearing forces, PLONG, carried by the sidewalls. Under this assumption, the moment at the center of the slab for any section and load condition is obtained as follows. Let

MWALL ≡ moment brought to floor slab by loads acting on sidewall stem, ft lbs per ft

PWALL ≡ sidewall direct force brought to floor slab, lbs per ft

PF ≡ pressure on footing projection, psf

WO ≡ overall width of basin = W + 2(TBV/12 + FTG), ft

CB ≡ direct compression in floor slab, see pages 56-57, lbs per ft
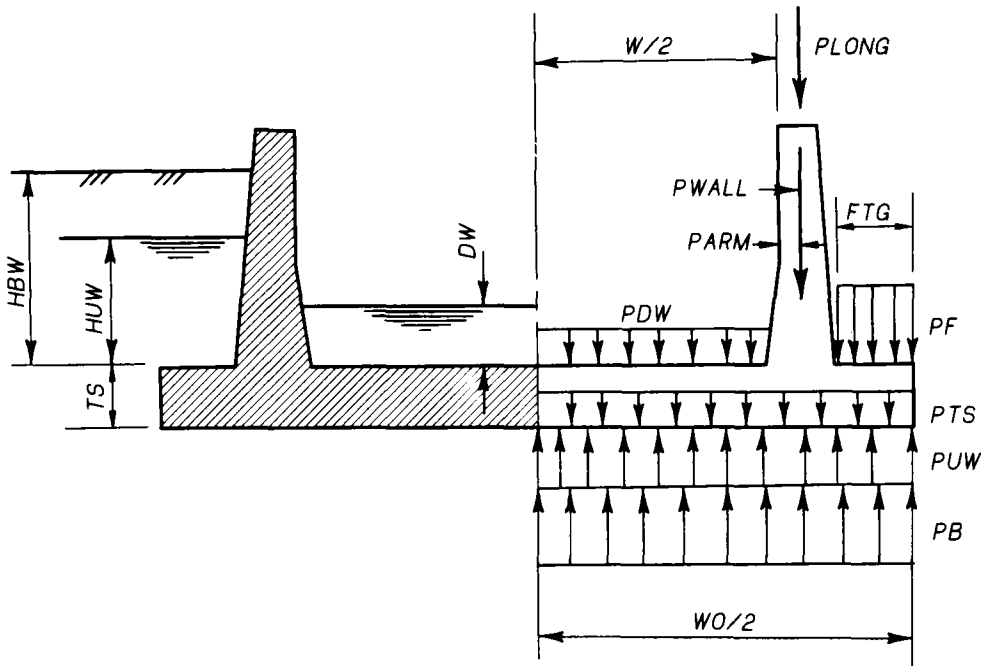
Figure 22. Loads for floor slab shear and bending

Then, in lbs per ft

$$PLONG = (PB + PUW - PTS)WO/2 - PF \times FTG - PDW \times W/2 - PWALL$$

So the center moment, MC, in ft lbs per ft, is

$$MC = (PB + PUW - PTS)WO^2/8 - PF \times FTG(WO/2 - FTG/2) - PDW \times W^2/8$$
$$- (PWALL + PLONG)(W/2 + PARM) + MWALL$$

Alternately, the longitudinal shearing forces are taken as uniformly distributed forces, ULONG, carried by the floor slab. Under this assumption, in psf

$$ULONG = PLONG/(WO/2)$$

and

$$MC = (PB + PUW - PTS - ULONG)WO^2/8$$
$$- PF \times FTG(WO/2 - FTG/2) - PDW \times W^2/8$$
$$- PWALL(W/2 + PARM) + MWALL$$

the larger absolute moment governs and the required slab thickness for preliminary design is taken as

$$TM = (0.003683(|MC| + CB(TS/2 - TADD)/12))^{1/2} + TADD$$

where TADD = 3.5 if MC is positive, or 2.5 if MC is negative.

If the required thickness exceeds the actual section thickness, the design is recycled as explained for floor slab shear.

Sliding. As previously noted, both LC #1 and LC #2 must be checked for adequacy of the basin against sliding. For each load condition, the resultant of the vertical forces including uplift, VNET, and the resultant of the horizontal driving forces, FSLIDE, must satisfy the relation

$$\frac{VNET \times CFSC}{FSLIDE} \geq SLIDER$$

where the forces VNET and FSLIDE are in lbs, and CFSC is the coefficient of friction between concrete and soil. For LC #2, see Figure 21

$$FSLIDE = FH2 \times W + FM \times W$$

where FM is discussed under the section "Momentum considerations." For LC #1, see Figure 8, take

$$FSLIDE = FH1 \times W - FT1 \times W$$

where

FH1 ≡ horizontal component of hydrostatic force due to HUP1, lbs per ft width of channel

FT1 ≡ horizontal component of hydrostatic force due to HTW1, lbs per ft width of channel.

Both FH2 and FH1 are multiplied by W to obtain respective net hydrostatic driving forces.

If either load condition sliding requirement is not satisfied, the weight on the structure is increased. This is done by first incrementing FTG up to MAXFTG. If these attempts are unsuccessful, then the floor slab thicknesses are incremented several times. If the sliding criteria is still unsatisfied, the design is abandoned, and a cancellation message is given.

Momentum changes at break-in-grade. The preceding analyses dealing with LC#2 do not include effects of momentum change that take place due to, and in the vicinity of, the break-in-grade. The following discussion pertains to cases of HTW2 ≤ D2. The force due to momentum change may be resolved into horizontal and vertical components. Both components decrease with the slope parameter, ZS. The horizontal component is of opposite sense to the momentum force, FM, discussed on pages 10-12 and hence would reduce the effect of FM. The vertical component acts downward on the basin and hence would reduce the basin weight required for flotation and would reduce the tendency for sliding of the basin. The vertical component would increase foundation bearing pressures. With the possible exception of this last effect in the presence of a weak foundation, it is probably conservative to neglect, that is, not to depend on, the effects of momentum change at the break-in-grade. This is especially so in view of the questionable nature of these forces.

Type (B)

Preliminary design of type (B) basins is similar to that of type (A) with three important differences. These differences are involved with sidewall bending, flotation, and determination of bearing (contact) pressures. They are due to the doweled, transverse articulation joint passing through the basin at the break-in-grade. With the transverse joint, footing projections, floor slab, and sidewall thicknesses are allowed to differ either side of the joint. The footing projections are FTGU and FTGD, and the floor slab thicknesses are TSBGU and TSBGD, upstream and downstream of the break-in-grade. Similarly, the sidewall thicknesses that may differ are TVU, TBVU, TBU and TVD, TBVD, TBD. See Figure 11 for corresponding type (A) thicknesses TV, TBV, and TB.

Type (B) basins have a vertical upstream end section, see Figure 2. Thus, with distances in feet

$$HS = J - N$$

$$LS = HS \times ZS$$

$$LTOT = LS + LB$$

Section heights, earthfill heights, tailwater depths, and uplift heads are obtained from the same expressions used with type (A), except that

$$HS1 = N$$

and

$$HB3 = HB + (J - HB) \times LB/LTOT.$$

Sidewall bending. Sidewall thicknesses upstream of the transverse joint are determined by the thicknesses required at the bottoms of sections 1, 2, and 3, see Figure 23, as was discussed earlier for type (A) basins.
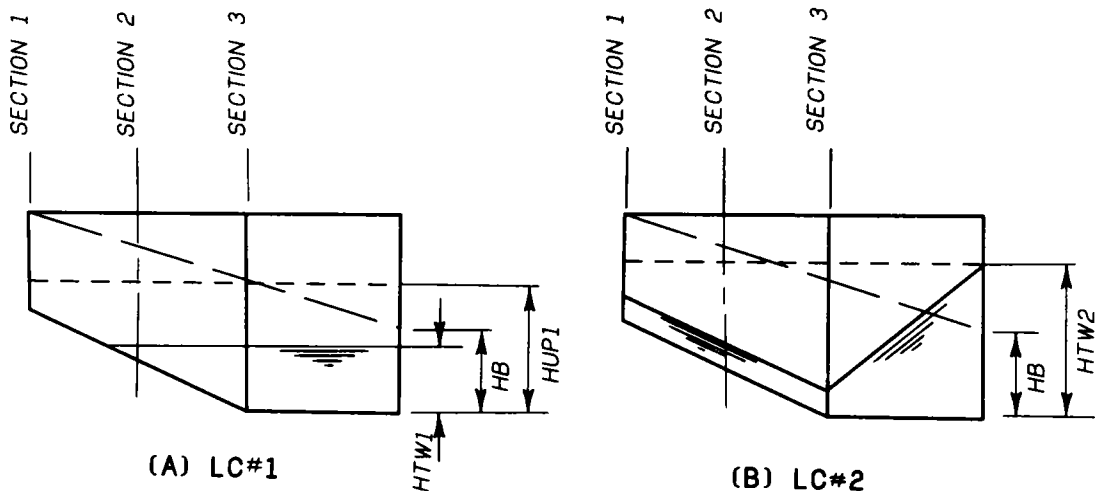
Figure 23. Considerations for sidewall bending, Type (B) basin

Thus, the upstream thicknesses TVU, TBVU, TBB, and TBU are obtained just as previously explained. Sidewall thicknesses downstream of the transverse joint are controlled by the thickness required at the bottom of section 3. Hence the downstream thicknesses TVD, TBVD, TBB, and TBD are

obtained from the procedure used to determine the thickness required at the bottom of a section.

Flotation. The upstream and the downstream portions of type (B) basins must satisfy flotation requirements separately. The various components of weight and uplift needed to make the flotation checks are similar to those for type (A) basins. Figure 24 indicates components of sidewall volumes, slab volumes, and footing pressures and loads.
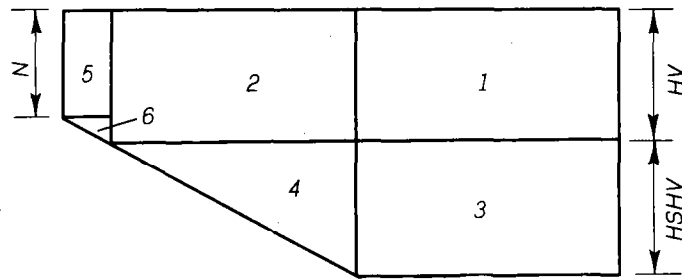
(A) SIDEWALL VOLUMES
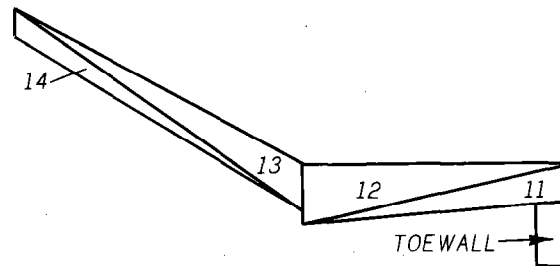
(B) SLAB VOLUMES
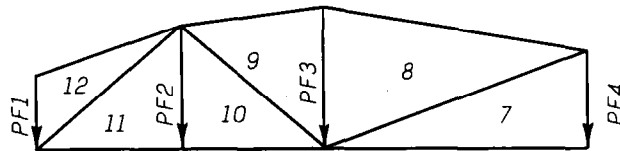
(C) FOOTING PRESSURES AND LOADS

Figure 24. Some type (B) components

Water volume and uplift components are essentially as shown in Figures 18 and 20.

Each portion of the basin, for each load condition, must satisfy the relation

$$\frac{SDOWN}{SUP} \geq FLOATR$$

where SDOWN is the sum of all downward forces for the portion and SUP is the sum of the uplift forces for the portion. Initial values for the upstream portion are

$$TSUP = TT + (TBVU - TT) \times N/J + 1$$

rounded up to the next integer, and

TSBGU = TBU + 1

FTGU = 0.

Initial values for the downstream portion are

TSBGD = TBD + 1.

TSDN = TBD + 1.

FTGD = 0.

If the flotation requirement is not satisfied for the portion under investigation, the corresponding footing projections and floor slab thicknesses are variously incremented up to MAXFTG and TBU + 10 or TBD + 10. If flotation remains unsatisfied the design is abandoned.

Bearing pressures. As previously noted, the transverse joint at the break-in-grade affects the structural behavior of this type of stilling basin. The precise behavior is admittedly uncertain. However, the doweled joint allows relative longitudinal translation of the two portions of the basin, does not allow relative transverse horizontal or vertical translation, and provides little moment resistance. The joint is therefore idealized as a hinge that is capable of transmitting shears and direct bearing between portions, but no moment. Figure 25 shows the resulting distribution of
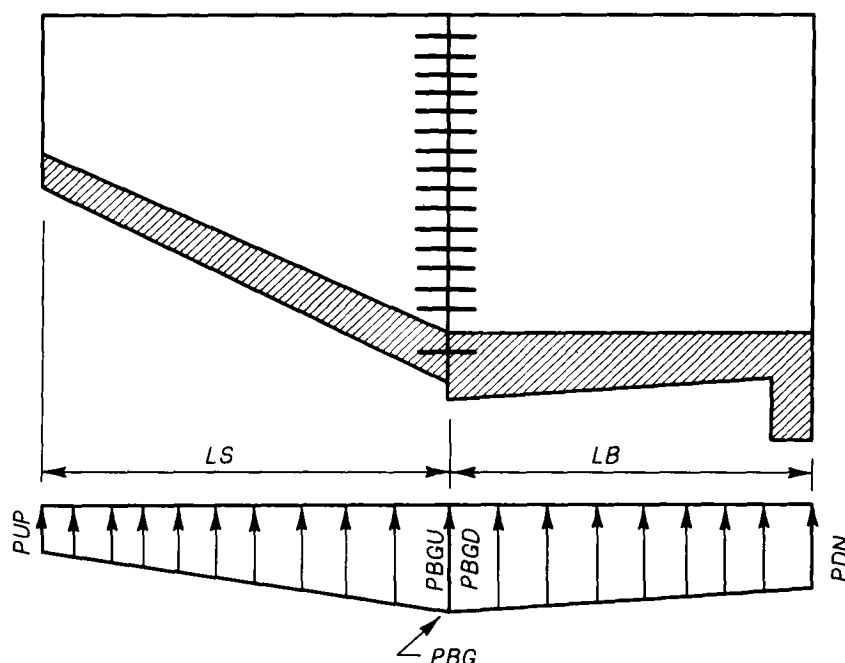
Figure 25. Distribution of bearing pressures
type (B) basin

bearing pressures. There are four unknown pressures PUP, PBGU, PBGD, and PND. By construction, vertical displacements immediately either side of the break-in-grade must be equal. Therefore bearing pressures immediately either side are equal assuming a constant modulus of the foundation. Thus

PBG $\equiv$ bearing pressure at the break-in-grade = PBGU = PBGD, psf.

The pressure distribution is therefore reduced to three unknowns. These unknowns may be evaluated by application of the statical equations

$\Sigma M_{HU} \equiv$ sum of moments of forces upstream of hinge,
about the hinge $= 0$

$\Sigma V \equiv$ sum of vertical forces $= 0$

$\Sigma M_{HD} \equiv$ sum of moments of forces downstream of hinge,
about the hinge $= 0$.

For the load condition under investigation, let

VRUP and VRDN $\equiv$ the resultants of the vertical forces
acting on the upstream and downstream
portions, respectively, lbs

MUP and MDN $\equiv$ the resultant moments of the upstream
and downstream forces, respectively,
about the hinge, ft lbs.

Figure 26 shows the equivalent beam, with its loading, created by these
assumptions and definitions.
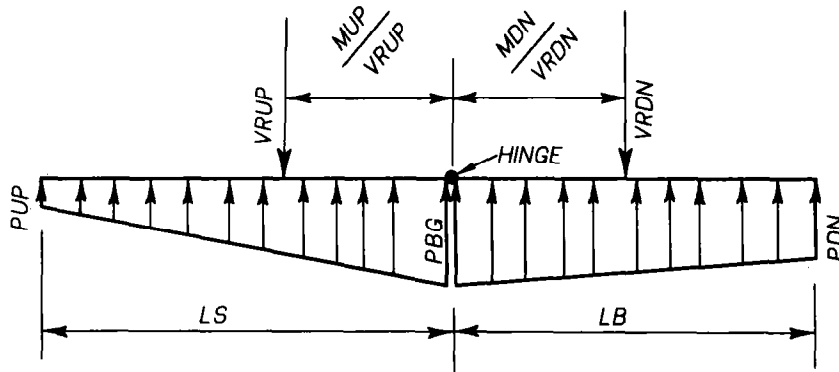
Figure 26. Equivalent beam and loading

The statical equations become

$$PUP(0.5 \times LS^2 \times 2/3)WOU + PBG(0.5 \times LS^2 \times 1/3)WOU = MUP$$

$$PUP(0.5 \times LS)WOU + PBG(0.5 \times LS \times WOU + 0.5 \times LB \times WOD)$$
$$+ PDN(0.5 \times LB)WOD = VRUP + VRDN$$

$$PBG(0.5 \times LB^2 \times 1/3)WOD$$
$$+ PDN(0.5 \times LB^2 \times 2/3)WOD$$
$$= MDN$$

from which PUP, PBG, and PDN in psf may be determined, noting

WOU $\equiv$ overall width of upstream portion of basin
$= W + 2(TBVU/12 + FTGU)$, ft

WOD $\equiv$ overall width of downstream portion of basin
$= W + 2(TBVD/12 + FTGD)$, ft

The horizontal components of the hydrostatic forces of Figures 8 and 9
enter into the evaluation of the moments, MUP and MDN, as does the net
momentum force FM x W. The horizontal forces, FH2 x W, FH1 x W, and
FT1 x W, as the case may be, are effectively shared in some way by both
portions of the basin. It is assumed that these forces are divided be-
tween the upstream and downstream portions, by direct bearing between

portions, in proportion to VNETU and VNETD where, for the portion

VNET = SDOWN - SUP

from flotation analyses. Thus, see Figure 27, the part of FH2 x W carried by the upstream portion is

FH2WU = FH2 x W x VNETU/(VNETU + VNETD)

and the part carried by the downstream portion is

FH2WD = FH2 x W x VNETD/(VNETU + VNETD).

The forces due to FH1 and FT1 are similarly divided.
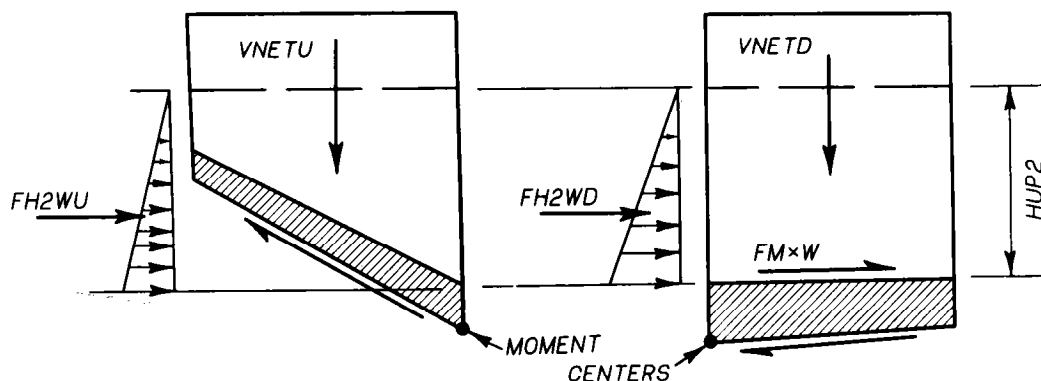
Figure 27. Division of horizontal force, LC#2

If either PUP, PBG, or PDN is negative, an attempt is made to increase the loading on the corresponding part of the structure. For example, if PUP is negative, then FTGU, TSBGU, and TSUP are incremented. Similarly, if any pressure exceeds the allowable bearing value, the corresponding footing projection is incremented in an attempt to spread the load.

Floor slab shear and bending. Required floor slab thicknesses will sometimes be governed by shear or bending moment. Cross sections are checked as described for type (A) basins. Four sections are investigated: the downstream end section, a section immediately downstream of the break-in-grade, a section immediately upstream of the break-in-grade, and the upstream end section. If any required thickness exceeds the actual section thickness, the design is recycled accordingly.

Sliding. Investigations into the adequacy of the basin against sliding are treated the same as described for type (A). That is

$$\frac{\text{VNET} \times \text{CFSC}}{\text{FSLIDE}} \geq \text{SLIDER}$$

where, for type (B) basins

VNET = VNETU + VNETD

for the load condition under investigation.

Type (C)

Preliminary design of type (C) basins is accomplished in two parts, first the design of the pavement slab and second the design of the retaining wall portion. The pavement slab is designed per unit of width. It is subjected to longitudinal shear and moment and must satisfy flotation, bearing, and sliding requirements. The retaining wall portion includes the design of many trial configurations. The toe length, X, varies from W/2 to 0. *
The design having the least volume is taken as best. For a particular value of X, the retaining wall portion is investigated for sidewall bending, flotation, bearing pressures, base slab shear and moment, and sliding. The bearing pressure distribution is three-dimensional and requires special treatment.

Pavement slab design. Loadings and bearing pressures are assumed constant along any section of the pavement slab at right angles to the longitudinal centerline of the basin. Hence no transverse bending exists in the pavement slab. The slab is therefore designed as a longitudinal beam of unit width.

Flotation. -- Flotation analyses are essentially as described earlier. Figure 28 shows the various components of slab volumes, volumes of water on the slab, and uplift volumes required to perform the computations. TPUP, TPBG, and TPDN are each set initially at 11 inches. They are incremented as necessary to obtain a set of values which satisfy the flotation criteria. TPBG is incremented most quickly, TPDN is incremented next most quickly, and TPUP is incremented least quickly. If the criteria remains unsatisfied after 500 trials, the design is abandoned.

Bearing pressures. -- The analysis of bearing pressures is straightforward. It parallels the procedure described for type (A) basins except on a per foot width basis. A possible case of LC #1 is illustrated in Figure 29. If the resultant vertical force per foot is VNET and the resultant moment about the moment center in ft lbs per ft is M, and other quantities are as previously defined, then

$$Z = M/VNET$$

$$E = LTOT/2 - Z$$

$$PAVER = VNET/LTOT$$

so, in psf

$$PDN = PAVER (1 + 6E/LTOT)$$

$$PUP = PAVER (1 - 6E/LTOT)$$

If either PUP or PDN is negative, corresponding slab thicknesses are incremented and the design is recycled. If either PUP or PDN exceeds the allowable bearing value, the design is abandoned.

Sliding. -- The pavement slab must satisfy

$$\frac{VNET \times CFSC}{FSLIDE} \geq SLIDER$$

where, for LC #1

$$FSLIDE = FH1 - FT1$$

*Except that X may not exceed 40. ft.
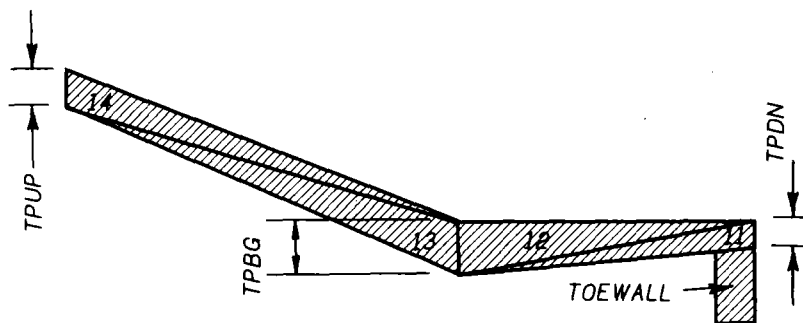
(A) PAVEMENT SLAB THICKNESSES AND VOLUMES
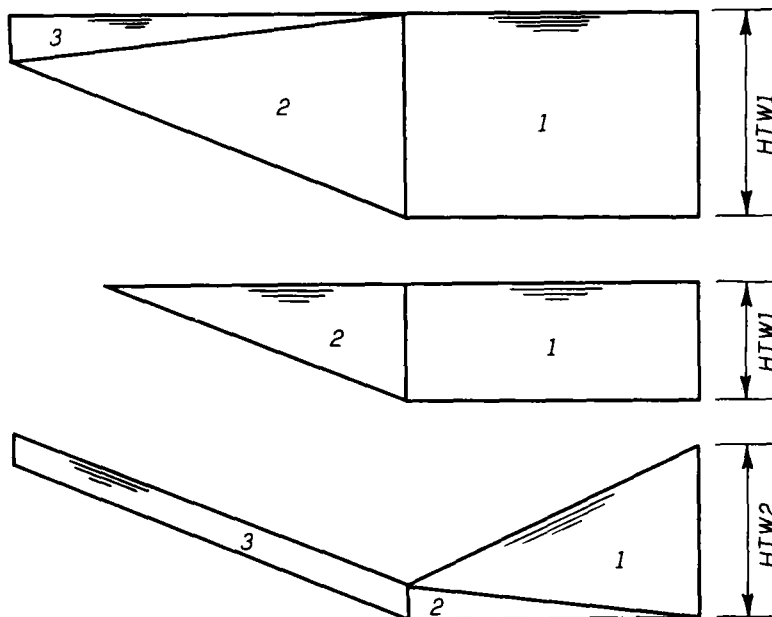
(B) POSSIBLE WATER VOLUMES, LC#1 AND LC#2.
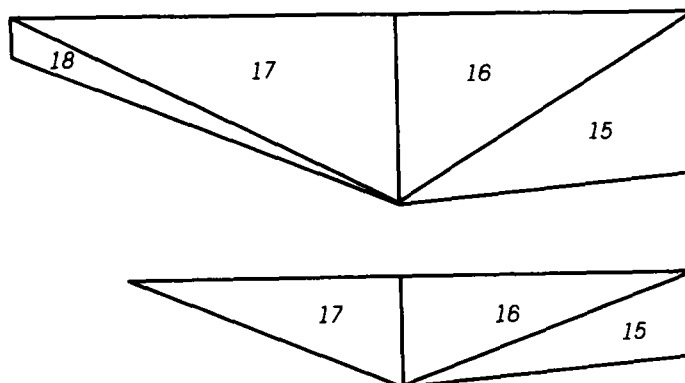
(C) POSSIBLE UPLIFT, LC#1 OR LC#2.

Figure 28. Pavement slab components

and for LC #2

$$FSLIDE = FH2 + FM$$

Figure 29. Determination of pavement slab
bearing pressures, LC#1

If the criteria is unsatisfied after a trial, then TPUP, TPBG, and TPDN
are equally incremented and another attempt is made.

Longitudinal shear and bending. -- The pavement slab thickness at any in-
terior section may be governed by either longitudinal shear or bending
moment. The thicknesses required by shear and moment are computed at a
series of sections between the downstream end of the pavement slab and
the break-in-grade, and at another series of sections between the upstream
end and the break-in-grade. If at any section the actual thickness is
less than that required for either shear or moment, the slab thicknesses
are suitably incremented and the design is recycled. The total number of
pavement design trials, due to any cause, is arbitrarily limited to 500.

Figure 30 indicates for LC #2, the load components used to obtain shear,
VP, in lbs per ft, and moment, MP, in ft lbs per ft at a distance, XDN,
in ft from the downstream end of the slab. From the sketch the water
depth, HX, in ft, is

$$HX = HTW2 - (HTW2 - D1) \times XDN/LB$$

and slab thickness, TX, in inches, is

$$TX = TPDN + (TPBG - TPDN) \times XDN/LB$$

the uplift head, UX, in ft, is

$$UX = HUP2 + TX/12$$

and the bearing pressure, PX, in psf is

$$PX = PDN - (PDN - PUP) \times XDN/LTOT.$$

Figure 30. Shear and moment in pavement slab,
LC#2

For LC #2, the uniform loading, FTOP, in lbs per ft per ft of width, acting on the floor of the basin is

$$FTOP = FM/LB$$

and

$$FBOT = FH2/LB + FTOP$$

with these quantities defined, VP and MP are readily determined. The required thicknesses are taken as

$$TXV = |VP|/840 + 3.5$$

$$TXM = (0.003683 \times |MP|)^{1/2} + 3.5$$

These thicknesses are compared with the actual thickness, TX, at the section. Computations for a section between the upstream end and the break-in-grade are similar but somewhat more complex.

Retaining wall portions. The design of the sidewall is the same as type (A) basins. However, the upstream end section is vertical, hence as with type (B) basins

$$HS = J - N$$

$$LS = HS \times ZS$$

$$LTOT = LS + LB$$

in terms of HBW, HWW, DW, TW, and ARM. These moments are summed over
the respective distances LB and LS to obtain the total moment due to
lateral forces. Several simplifying assumptions are made to obtain these
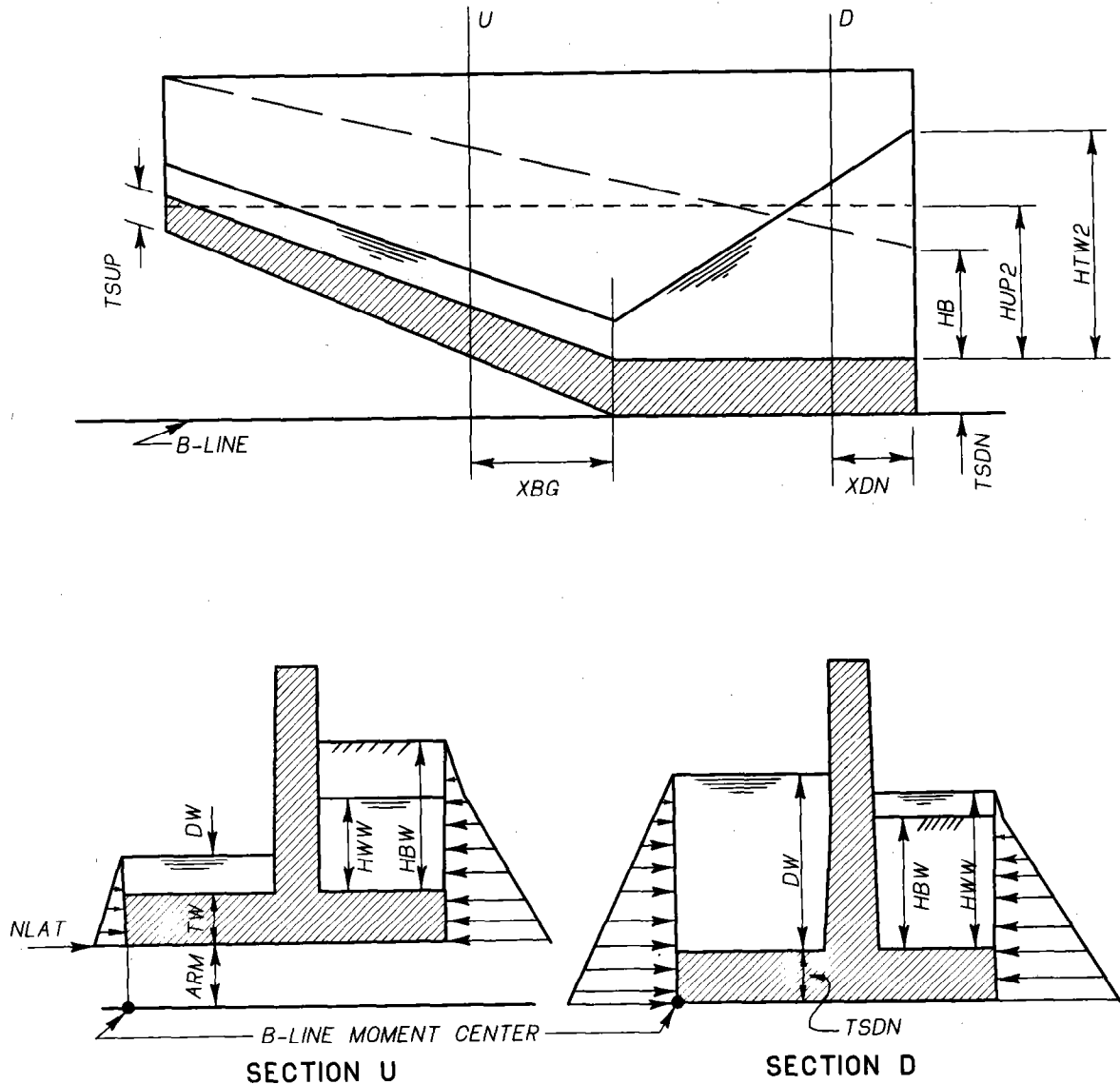
Figure 32. Retaining wall portion lateral force moments,
LC#2

moment expressions. A waterstop between the pavement slab and the retain-
ing wall base is assumed effective at the elevation of the bottom of the
base slab. The thickness of the level base slab is taken as TSDN in these
computations. The retaining wall portion is assumed to bear against the
pavement slab. NLAT, shown on the upstream section, is this direct force.
It is the force required for lateral equilibrium of the section. Thus the
downstream section working values, for the case shown are

$$HBW = HB + (HB3 - HB) \times XDN/LB$$

$$HWW = HUP2$$

$$DW = HTW2 - (HTW2 - D1) \times XDN/LB.$$

The upstream section working values, for the case shown, are

$$HBW = HB3 - (HB3 - HB1) \times XBG/LS$$

$$HWW = HUP2 - XBG/ZS$$

$$DW = D1$$

$$TW = TSUP + (TSDN - TSUP) \times (LS - XBG)/LS$$

$$ARM = TSDN/12 + XBG/ZS - TW/12$$

Working values for load condition No. 1 are similar. With the working values known, the moments are readily expressed, the summations made, and the bearing pressures determined.

If any bearing pressure is negative, the corresponding base slab thickness and FTG are incremented. If any bearing pressure exceeds the allowable, FTG is incremented in an attempt to spread the total load.

Base slab shear and bending. -- Required base slab thicknesses will sometimes be governed by shear or bending moment. Three cross sections are checked: the downstream end section, the section at the break-in-grade, and the upstream end section. Both load conditions are investigated. Figure 33 shows typical loadings. PBH and PBT are the bearing pressures at the heel and toe resulting from the preceding analyses of bearing. The other loadings are as defined for type (A) basins. Shear and moment are computed at the face of the sidewall. Longitudinal shears are treated both ways as previously described. If it is assumed carried by the sidewall, shears and moments at the faces of the sidewall are unaffected by PLONG. If the longitudinal shears are assumed carried by the base slab then
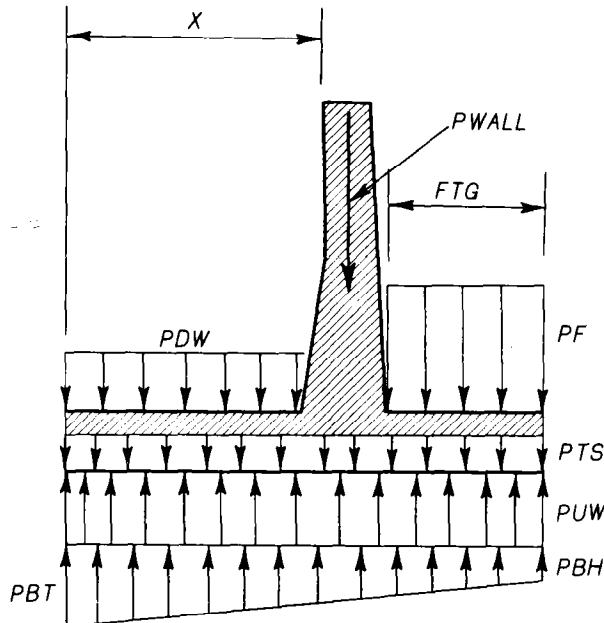
Figure 33. Loadings for base slab shear and moment

$$ULONG = (PBT + PBH)/2 + PUW - PTS - (PF \times FTG + PDW \times X - PWALL)/WOB$$

and the face shear and moment expressions must include ULONG. The assumption leading to the larger required thickness is taken as controlling. If any required thickness exceeds the actual slab thickness, the design is recycled accordingly.

Wingwall

The wingwall is considered to act essentially independently of the basin proper. The wingwall is vertical and of constant thickness. It is articulated from the basin sidewall as shown in the layout drawing of Figure 4. The wingwall footing and toewall are monolithic with the footing and toewall of the basin proper. Design investigations include bending of the wingwall and wingwall footing, overturning, and sliding. Figure 34 shows the wingwall section assumed for design. The toewall below
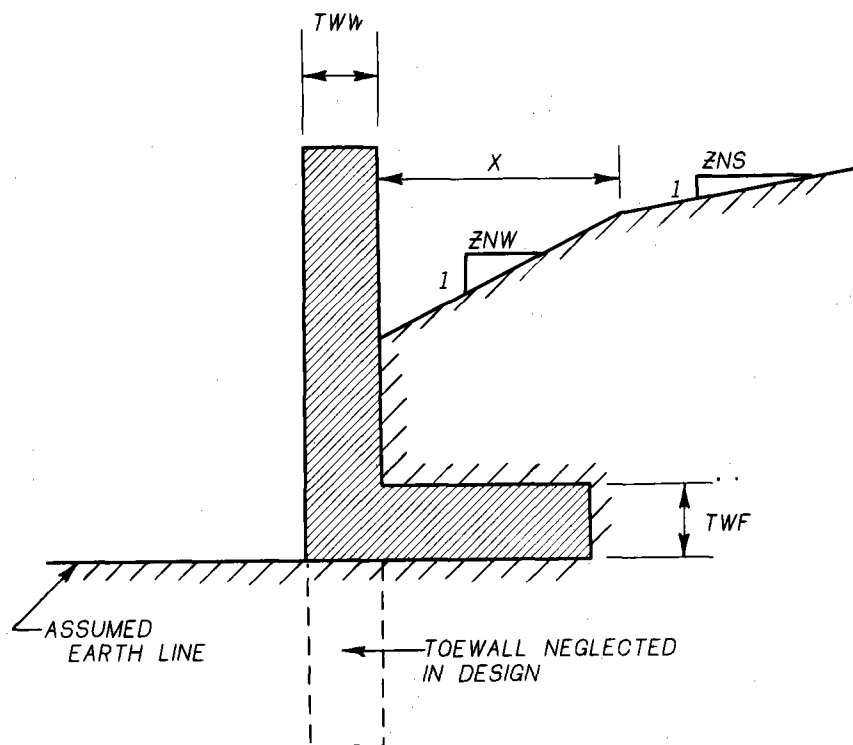
Figure 34. Wingwall design section

the footing is assumed non-existent. The earth line in front of the wingwall is horizontal at the elevation of the bottom of the footing. The earthfill slopes at the back of the wall are defined below.

The sidewall and wingwall are shown as line diagram idealizations in Figure 35. Earthfill surfaces are also shown. The surface of the earthfill against the wingwall varies linearly from HB at the articulation joint to 1.0 ft above the top of the footing at the downstream end of the wingwall. These surfaces give rise to three slope parameters of interest, they are

ZPS ≡ slope parameter for the earthfill adjacent to the sidewall in the direction parallel to the sidewall

ZNW ≡ slope parameter for the earthfill adjacent to the wingwall in the direction normal to the wingwall

ZNS ≡ slope parameter for the earthfill adjacent to the sidewall in the direction normal to the wingwall.

Thus,

$$\text{ZPS} = (\text{LTOP or LTOT})/(\text{J} - \text{HB})$$

$$\text{ZNW} = (\text{J} - 1)/(\text{HB} - 1)$$

$$\text{ZNS} = \text{ZPS} \sqrt{2}$$

PARTIAL PLAN

PARTIAL ELEVATION
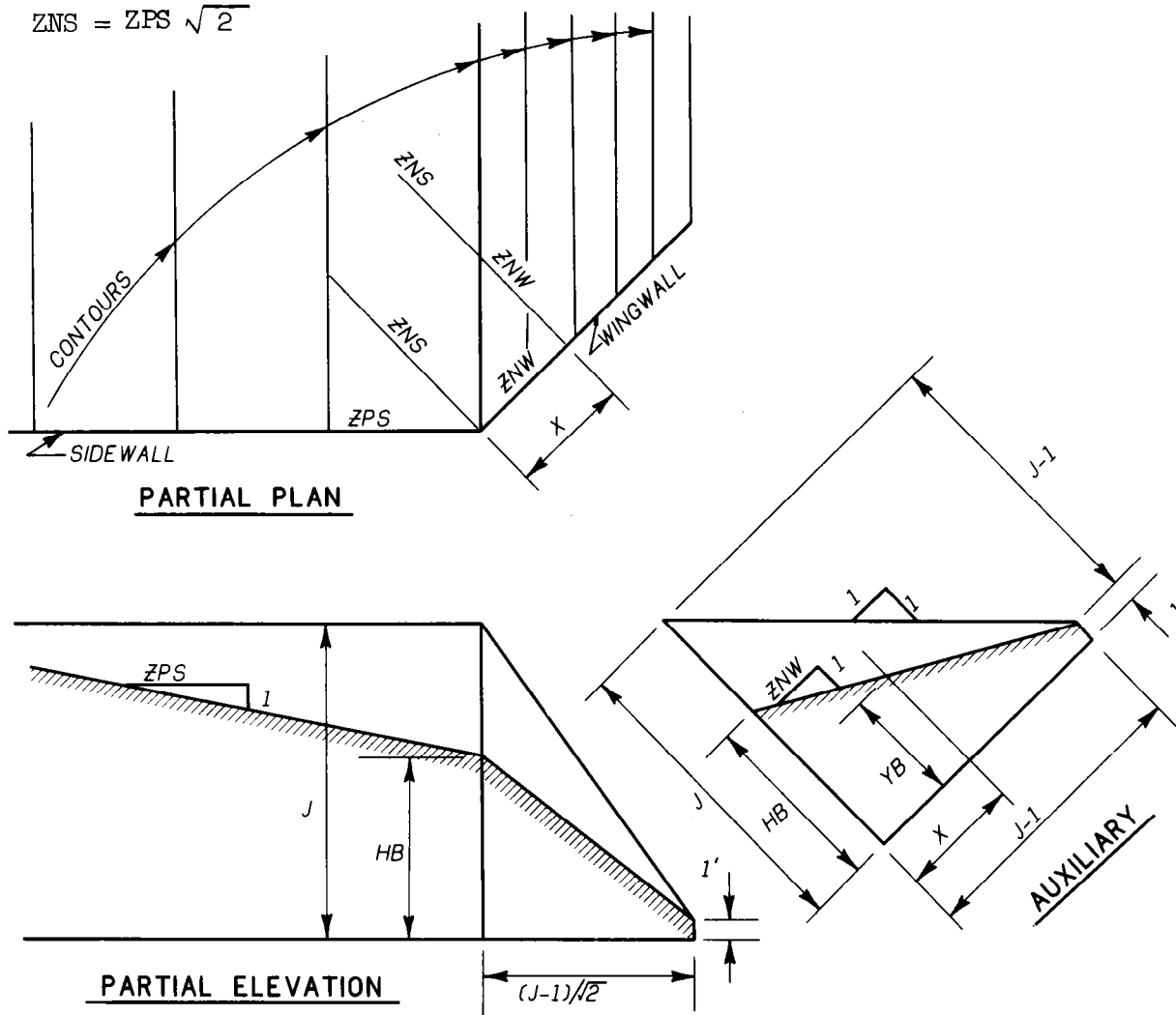
Figure 35. Wingwall earthfill surfaces and slopes

The earthfill height, YB, in ft above the top of the footing for any distance, X, in ft from the articulation joint is

$$\text{YB} = \text{HB} - \text{X}/\text{ZNW}.$$

With the sloping earthfill shown in Figure 34, a brief might be presented for assuming that lateral earth pressures are inclined from the horizontal. That is, they have vertical and horizontal components. This is not done herein. Lateral earth pressures are horizontal and vary directly with KO and distance below the surface. To include a vertical component would be unconservative since it would be a stabilizing force (in overturning and sliding analyses) whose existence and magnitude are uncertain.

Loading conditions. Wingwall design requires the investigation of more than the two load conditions necessary for the design of the basin proper. Critical loading often occurs at an intermediate load condition between

LC #1 and LC #2. Furthermore, different load conditions are critical for different functions. Therefore, as shown schematically in Figure 36,
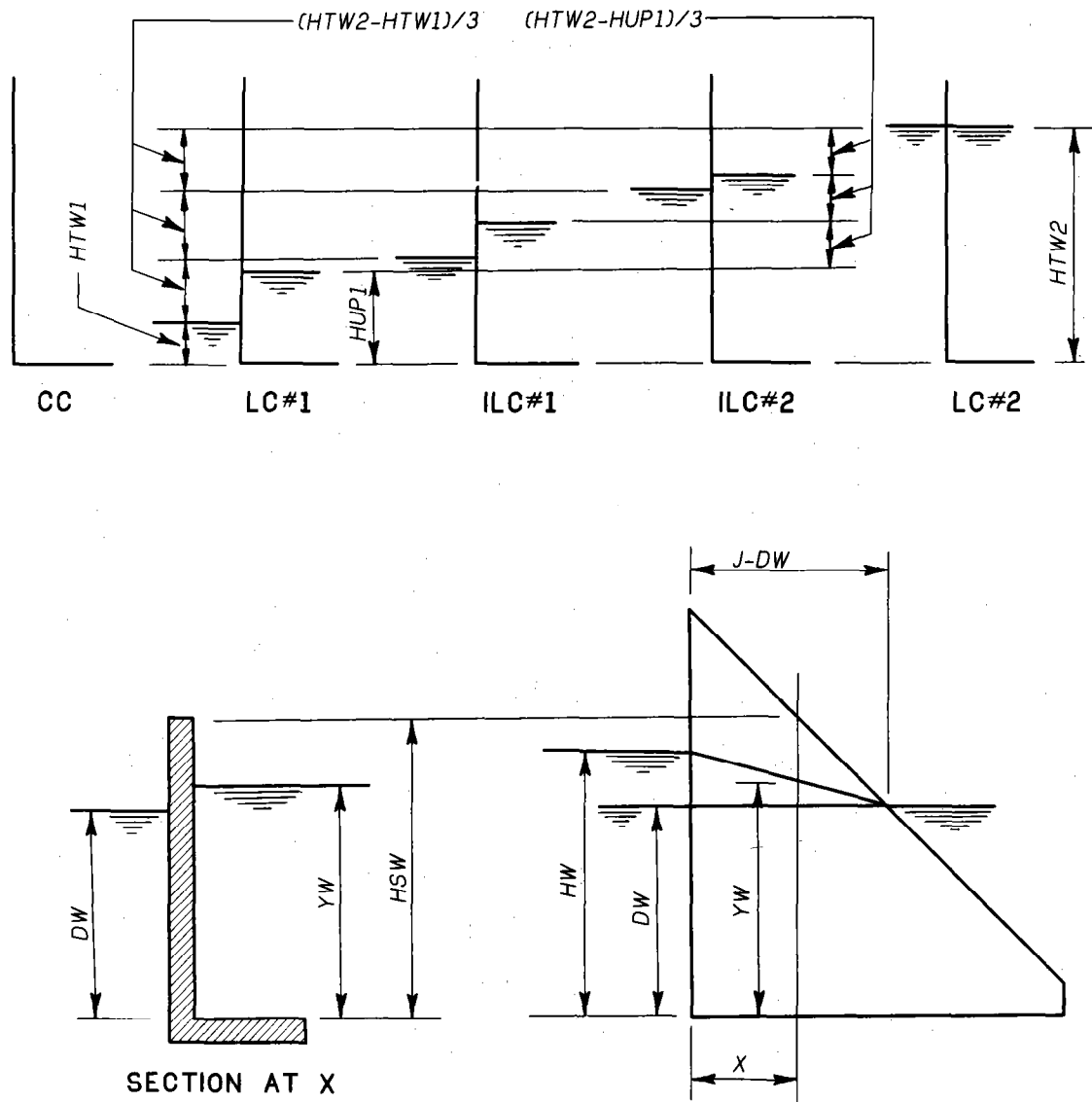
Figure 36. Load conditions for wingwall design

two intermediate load conditions are created for use in design of wingwalls. These are ILC #1 and ILC #2. The construction condition, CC, with no water either side of the wingwall, is included as still another loading since it will sometimes control a function. For LC #2 the water surface both sides of the wall is HTW2 above the top of the footing. Let

HW ≡ uplift head above top of footing at the articulation joint, for the load condition under investigation, in ft

DW ≡ tailwater depth above top of footing for the load condition under investigation, in ft.

Then the water height, YW, in ft on the back face of the wingwall for any distance, X, is

$$YW = HW - (HW - DW) \times X/(J - DW)$$

when $X < (J - DW)$. It is

YW = DW

when $X \geq (J - DW)$.

The water depth on the front face of the wall is constant at DW. Water surfaces are assumed horizontal normal to the wingwall.

Wingwall bending. The thickness of the wingwall is determined by shear or moment and direct force at the bottom of the wall at the section adjacent to the articulation joint. All load conditions indicated in Figure 36, except LC #2, are investigated to obtain the maximum required thickness. Load condition No. 2 cannot produce maximum shear or moment at the base of the section. Figure 37 illustrates a possible case for one load condition.
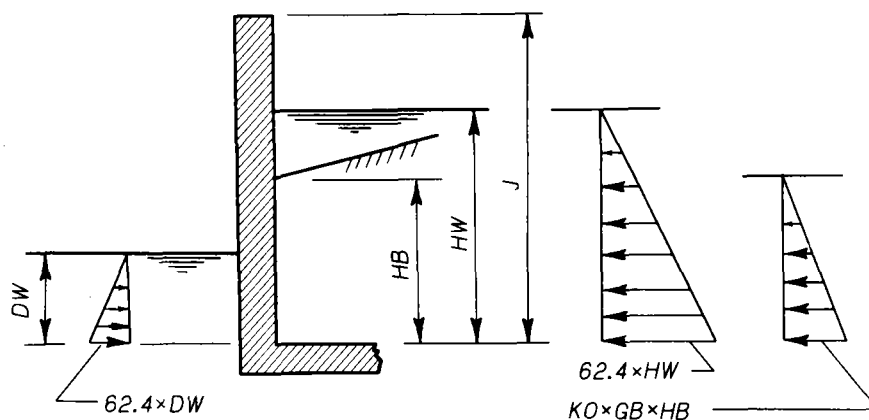
Figure 37. Determination of wingwall thickness

The thickness required by shear is determined directly. The thickness required by moment and direct force is determined by an iterative process. The shear is, in lbs per ft

$$V = 31.2(HW^2 - DW^2) + 0.5 \times KO \times GB \times HB^2$$

so the required thickness for shear is, in inches

$$TS = V/840 + 2.5$$

The moment is, in ft lbs per ft

$$M = 10.4(HW^3 - DW^3) + 0.5 \times KO \times GB \times HB^3/3.$$

The direct force for a thickness, TM, is

$$N = 12.5 \times J \times TM$$

so the equivalent moment is

$$M_s = M + N \times (0.5 \times TM - 2.5)/12$$

and the required thickness for moment and direct force is, in inches

$$TM = (0.003683 \times M_s)^{1/2} + 2.5$$

The computed required TM and the assumed TM must agree.

These computations are repeated for the four load conditions. The wingwall thickness, TWW, is the largest of all of the above required thicknesses.

Overturning. Initial values of wingwall footing projections, BUP and BDN, are determined by considering the wingwall as an independent wall and making it stable against overturning. Required footing projections are determined by analyzing slices of unit width at the four sections indicated by Figure 38. Each slice must be stable by itself. Individual slices are analyzed, rather than the entire wingwall as a unit, because of the complexity of treating general bearing on an unsymmetrical bearing area.
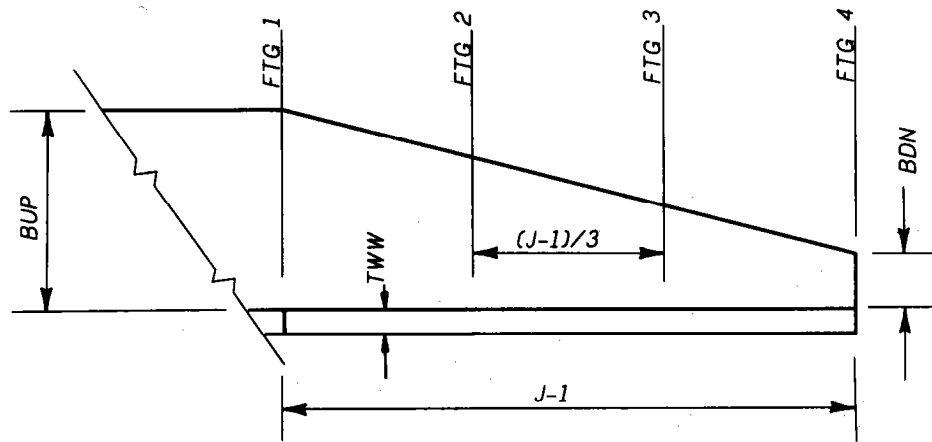
Figure 38. Wingwall footing projections

The required footing projections are found at each of the four sections. Then BUP and BDN are selected from the requirement that footing projections vary linearly between BUP and BDN. If any required projection at sections 2, 3, or 4 exceeds the required projection at section 1, the projection for the entire footing is made constant at the largest required value. Each section is investigated for all load conditions shown in Figure 36 to obtain the maximum required projection at the section. Figure 39 indicates the analysis for a possible case at a particular section and load condition. The distance from the section under consideration to the wingwall articulation joint is X. X is also the distance from the back of the wall to the break in earthfill slopes. Current values of footing thickness, TWF, and footing projection, FTG, are investigated. First trial values are TWF = TWW and FTG = 1. Footing pressures, lateral water and earth pressures, uplift pressures, footing dead load, and wall weight are determined for the current values. Footing pressures vary linearly between the three points: back of the wall, X from the wall, and edge of footing.

With the loads known, moments about the toe and summation of vertical forces locates VNET at Z from the toe. If VNET is located outside the base width, WOB, that is Z is negative, then FTG is incremented for another trial. If VNET is located within the base, within WOB/3 of the toe, then PBH would be negative so again FTG is incremented for another
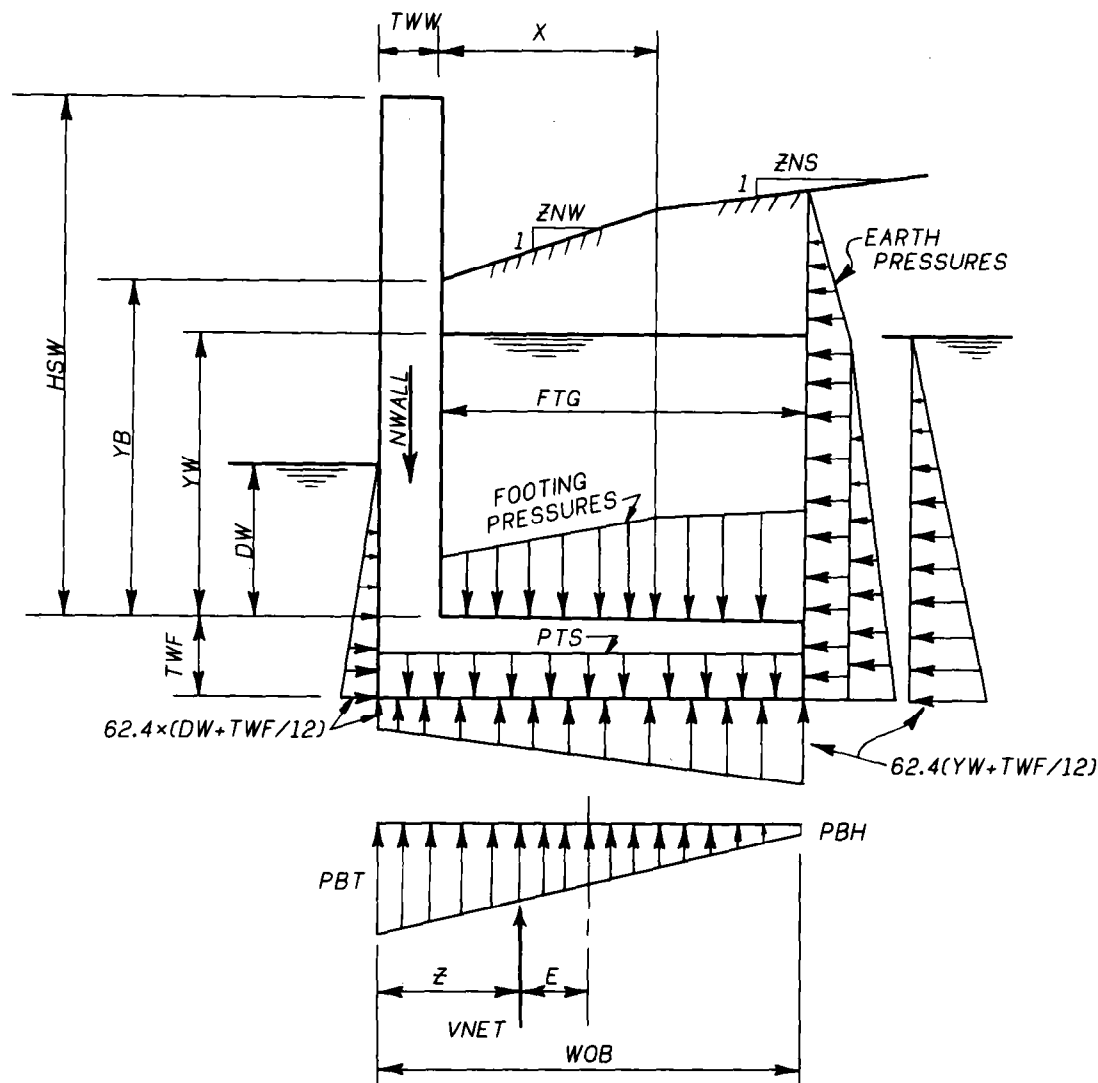
Figure 39. Wingwall overturning and bearing

trial. If VNET is located within the middle third of the base, the section is safe against overturning and the contact bearing pressures, PBT and PBH, are computed in the usual way. If the higher pressure exceeds the allowable value, taken as

$$\text{PALLOW} = 2000 + \text{GB} \times (\text{YB} + \text{TWF}/12)$$

FTG is again incremented. Each trial recycles the footing design back to the first load condition for the section under investigation.

When bearing pressure requirements are satisfied, footing thickness required for moment is determined. The critical section for moment is at the face of the wingwall. If the required thickness is more than the actual thickness, TWF is incremented and the footing design is recycled starting at the first location, (section 1 of Figure 38) and the first load condition. Analyses have shown that shear seldom controls footing thickness in these wingwalls. Hence the thickness required for shear is

only checked, and the design recycled if necessary, in detail design.

Sliding. The basin proper is designed to satisfy longitudinal sliding requirements, by itself. Therefore, no additional sliding force should be brought to the basin by the wingwalls. This means the wingwalls should be adequate themselves to resist sliding in the longitudinal direction of the basin. (Any tendency of the wingwall to slide in a transverse direction, toward the center of the channel, is resisted by the wingwall-to-basin tie discussed in the next section.) Let the resultant horizontal driving force normal to the sidewall be FSLIDE, see Figure 40. This force is obtained by summing, over the length of the sidewall, the net horizontal forces per unit length, HNET, at each of
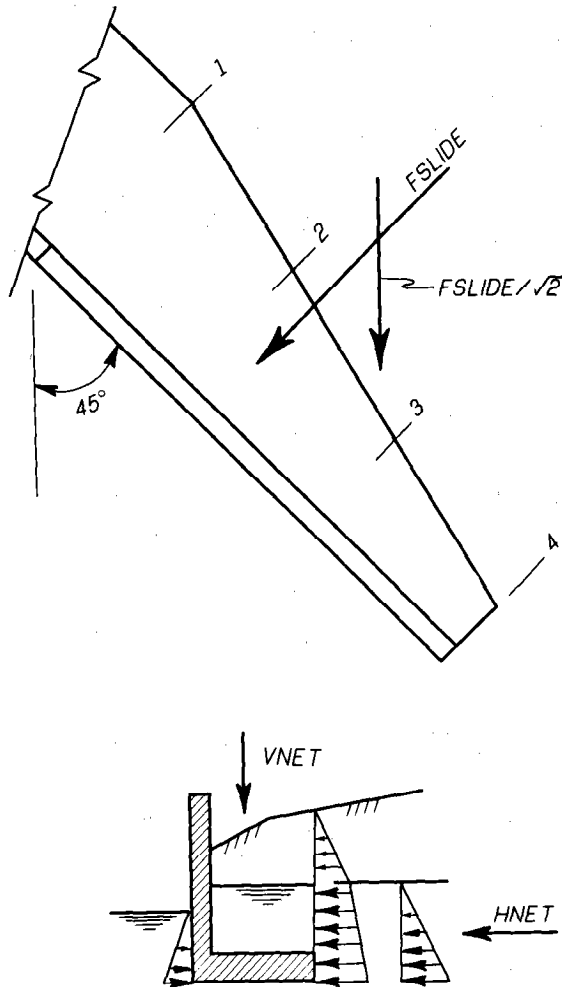
Figure 40. Longitudinal sliding of wingwall

the four sections. HNET is obtained from the indicated horizontal forces, for a particular section and load condition. Thus

$$\text{FSLIDE} = (\text{HNET1}/2 + \text{HNET2} + \text{HNET3} + \text{HNET4}/2) \times (J - 1)/3.$$

Similarly, if VWING is the resultant vertical force on the wingwall, and VNET is the resultant per unit length, then

$$\text{VWING} = (\text{VNET1}/2 + \text{VNET2} + \text{VNET3} + \text{VNET4}/2) \times (J - 1)/3.$$

The longitudinal component of FSLIDE is FSLIDE/$\sqrt{2}$. To adequately resist sliding, the wingwall must satisfy the relation

$$\frac{1.4142 \times \text{VWING} \times \text{CFSC}}{\text{FSLIDE}} \geq \text{SLIDER}$$

for each load condition of Figure 36.

If the above relation is not satisfied for any load condition, BUP and BDN are incremented equally. The design is recycled to the start of the overturning analysis with the new footing projection values. This is necessary because the wingwall footing thickness, TWF, may require incrementing with the larger footing projections.

Wingwall-to-basin tie. A structural tie is provided between the wingwall footing and the footing and floor slab of the basin proper. This wingwall-to-basin tie prevents rotation of the wingwall about its junction with the basin sidewall and thus effectively prevents any possibility of transverse sliding of the wingwall. The wingwall-to-basin tie is designed for the full moment due to the resultant horizontal force, FSLIDE, of Figure 40. This is admittedly conservative in that it completely neglects any frictional resistance that is developed. Let MTIE be the full moment, in foot lbs, and ARM be the moment arm shown in Figure 41. Then, in inches

$$\text{ARM} = \text{BUP} \times 12 - 6 - \text{TWW}/2$$
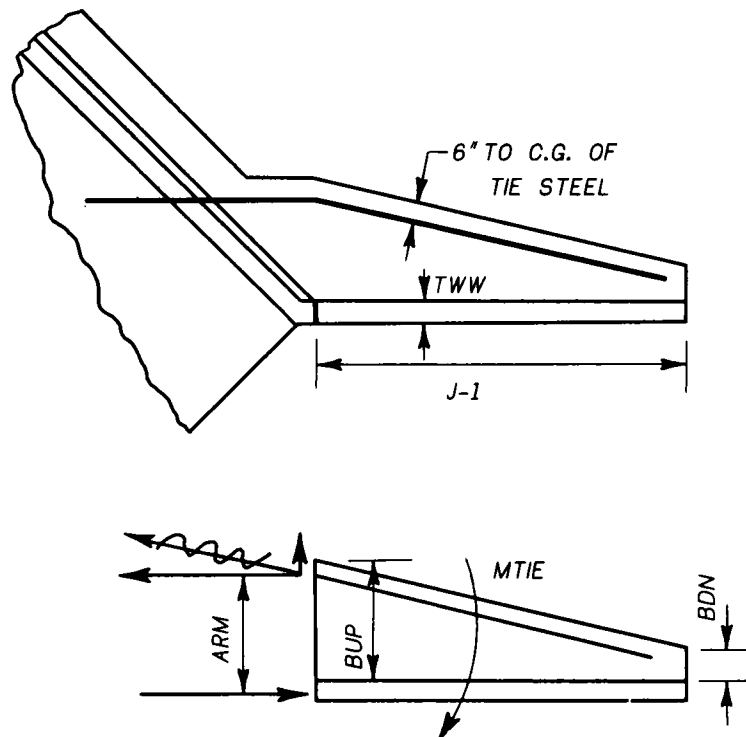
Figure 41. Wingwall-to-basin tie steel area

and the required area of the tie steel, in sq. in., just downstream of the section through the articulation joint is approximately

$$\text{ATIE} = \frac{\text{MTIE} \times 12}{20,000 \times \text{ARM}} \times \frac{((\text{J} - 1)^2 + (\text{BUP} - \text{BDN})^2)^{1/2}}{(\text{J} - 1)}$$

Detail Designs

With the two exceptions of the longitudinal steel in the pavement slab of type (C) stilling basins and the wingwall-to-basin tie steel, detail design is concerned with the determination of requirements for transverse steel. Transverse steel in the pavement slab and longitudinal steel in all other elements need only satisfy temperature and shrinkage (T and S) requirements.

Each detail design begins with the set of trial dimensions obtained in the preliminary design. Thicknesses are incremented, and the design recycled, whenever it is discovered compression steel would otherwise be required to hold bending stresses to allowable working values. A wingwall detail design accompanies the detail design of every basin requested. Required steel area and maximum allowable steel spacing are computed at a sufficient number of points to adequately define the steel requirements of the stilling basin. Steel areas given always satisfy T and S requirements. In the sidewall, the points are the same for each stilling basin type. In the floor slabs of types (A) and (B) basins and in the base slab of type (C) basins, the points are similarly located and numbered so that there is little difficulty in switching thought from one type to another. Schematic steel layouts are shown for sidewalls, floor and base slabs, and wingwalls. The actual steel is selected by the designer once he knows the steel requirements at the various points.

Sidewall steel

Steel areas and spacings are determined for the eleven points defined in Figure 42. Points 1 through 10 are on the inclined steel in the back of the wall. The vertical steel in the front of the wall need only be provided in T and S amounts with the possible exception of steel in the vicinity of point 0, discussed later.

Refer to Figures 14 and 42. Study of sketch (A) of Figure 14 shows that for LC #1 the steel requirement at points 2, 3, 4, or 5 equals or exceeds the steel requirement at any point to the right of, and at the same elevation as, the point under consideration. Observation of sketch (B) of Figure 14 for LC #2 shows that similar statements apply if the water depth, D1, in the basin is neglected for points 2, 3, and 4.

The steel requirements for the vertical steel in the back face of the sidewall are therefore evaluated as follows. The requirements at points 1 through 5 and at corresponding points 6 through 10 at the break-in-grade section are determined. Note that it is often convenient or necessary to alter the wall steel layout at the break-in-grade section. The steel determined for point 3 is adequate between point 3 and point 8. The steel determined for point 8 is adequate between point 8 and the point on the downstream end section at the same elevation as point 8. Corresponding statements are true for similar pairs of points. The steel required at point 5 is reported for purposes of interpolation. Any interpolation should assume straight-line variation between points. For type (B) basins, the thicknesses of the upstream portion are used with points 1 through 5 whereas the thicknesses of the downstream portion are used with points 6 through 10. For types (A) and (C) basins, these thick-

54
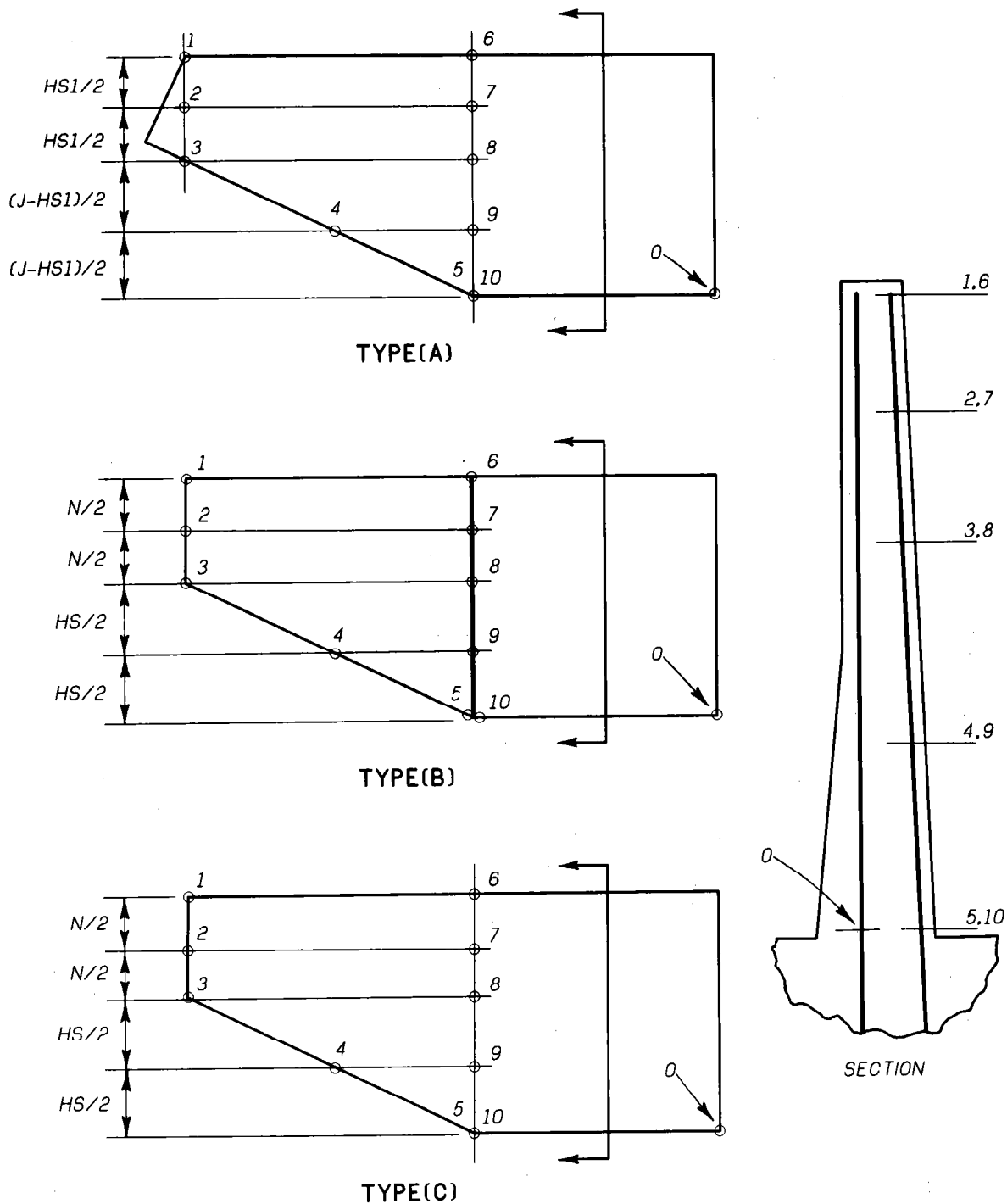
Figure 42. Sidewall steel layout and point locations

nesses are the same so points 5 and 10 are actually the same point.

Figure 43 illustrates a possible loading situation. It might be LC #1 or LC #2. The section under consideration is located at distance, Z,
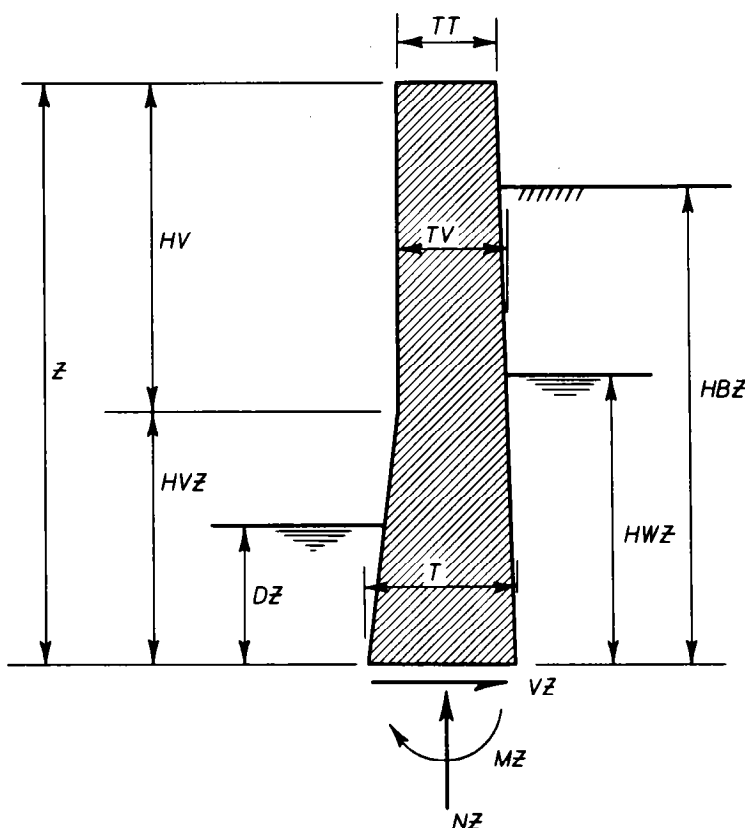
Figure 43. Sidewall steel design

from the top of the wall. Shear, VZ, in lbs per ft; moment, MZ, in ft lbs per ft; and direct force, NZ, in lbs per ft are determined for the section and loads. The required steel area for this MZ and NZ may be obtained as explained in TR-42. If the current effective depth is inadequate without using compression steel, the bottom thickness, TBV, and hence TB, is incremented and the wall steel design is begun again. When the effective depth is adequate, the maximum allowable spacing of the steel at this section is given, in inches, by

$$SZ = 10,015 \times (T - 2.5)/VZ$$

as explained on page 47 of TR-42.

As noted earlier, the water surface on the outside of the basin side-walls, for LC #2, is taken conservatively at HTW2 for sidewall bending analyses. However, when HTW2 > HUP2, tension may occur in the steel in the front of the wall at and in the vicinity of point 0 on the assumption the water surface on the outside of the wall is at HUP2. Therefore a steel requirement is reported for point 0 only when HTW2 > HUP2 and tension is computed to exist at this section with

$$Z = J$$

$$HBZ = HB$$

$$HWZ = HUP2$$

$$DZ = HTW2.$$

Floor slab steel

Steel areas and spacings are determined at twelve points in the floor slab in each of three sections for type (A) basins and in each of four sections for type (B) basins. Both LC #1 and LC #2 are investigated. The three type (A) basin sections are the downstream end section, the break-in-grade section, and the upstream end section. The four type (B) basin sections are the downstream end section, a section immediately downstream of the break-in-grade, a section immediately upstream of the break-in-grade, and the upstream end section. The toewall is neglected in computing the downstream end section steel requirements. Figure 44 gives the location and numbering of the twelve points in each section.
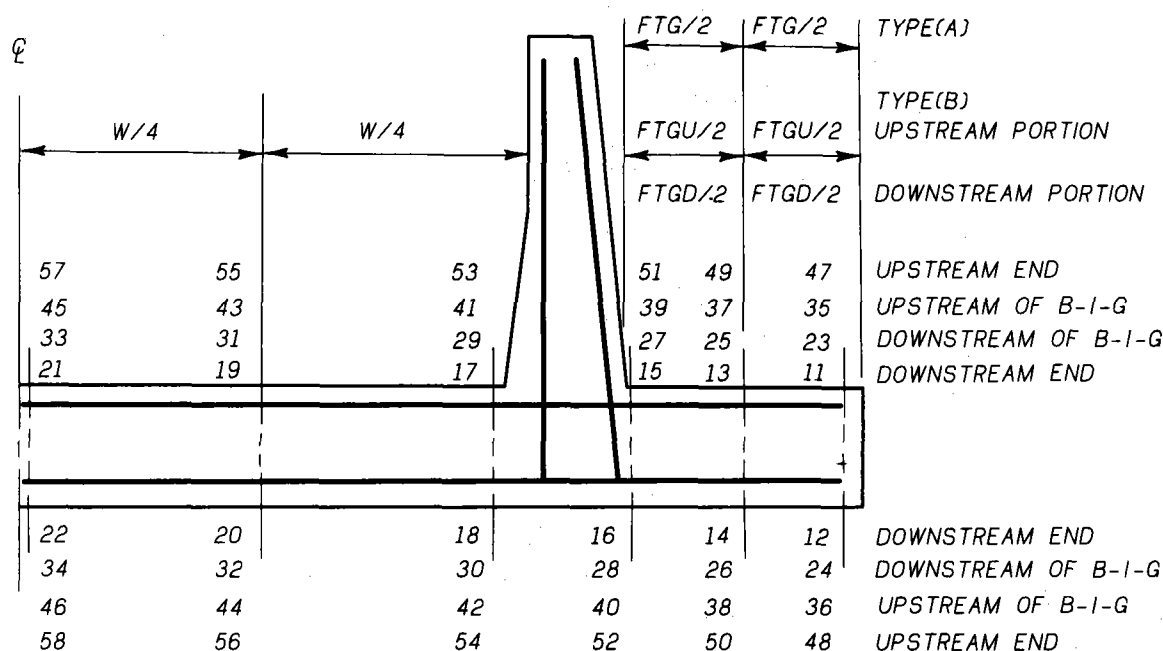
NOTE:

FOR TYPE(A) POINTS 35-46 ARE OMITTED AND POINTS 23-34 ARE AT BREAK-IN-GRADE SECTION.

Figure 44. Floor slab steel layout and point locations

In accordance with previous discussion, see page 26, bearing pressures are assumed constant along any transverse section of the basin. Figure 22 shows loads and pertinent variables involved. For the case shown, the direct compressive force in the footing projections, in lbs per ft, is

$$CF = (KO \times GM \times HDIFF + (KO \times GB + 62.4)(HUW + TS/24)) \times TS/12$$

where HDIFF = HBW - HUW. The horizontal loading on the wall is

$$HWALL = KO \times GM \times HDIFF \times (HDIFF/2 + HUW)$$
$$+ KO \times GB \times HUW^2/2 + 62.4(HUW^2 - DW^2)/2.$$

Thus the direct compressive force in the floor slab between the sidewalls, in lbs per ft, is

CB = CF + HWALL.

Shear and moment values at any location are also computed directly by statics. Longitudinal shear is treated both ways described on pages 28 and 29.

With moment and direct force, and shear known at any location, required steel area and maximum steel spacing may be evaluated as explained in TR-42. The effective depth is (TS-3.5) for positive moment, that is, moment producing tension in the bottom of the slab, and (TS-2.5) for negative moment. If the effective depth is inadequate, the slab thickness is incremented and the floor slab steel design is begun again. For negative moment, a check is made to determine if the top steel qualifies as "top bars" with regard to spacing of steel for bond. The spacing of "top bars" is given by $S = 7093 \times (T - 2.5)/VZ$ in accordance with TR-42.

Base slab steel

Steel areas and spacings are determined at twelve points in the retaining wall base in each of three sections for type (C) basins. The sections are the downstream end section, the break-in-grade section, and the upstream end section. Figure 45 gives the location and numbering of the points.

	X/2	X/2		FTG/2	FTG/2	
57	55	53	51	49	47	UPSTREAM END
33	31	29	27	25	23	BREAK-IN-GRADE
21	19	17	15	13	11	DOWNSTREAM END

22	20	18	16	14	12	DOWNSTREAM END
34	32	30	28	26	24	BREAK-IN-GRADE
58	56	54	52	50	48	UPSTREAM END
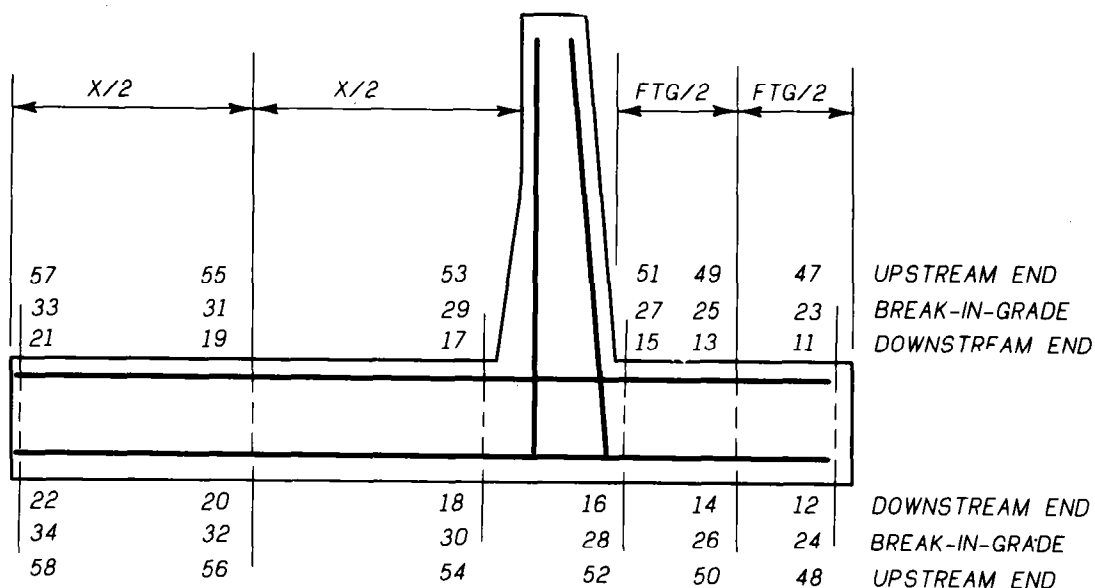
Figure 45. Base slab steel layout and point locations

Bearing pressures at the toe and heel of the upstream and downstream end sections are obtained as described for preliminary design of type (C) retaining wall portions. Bearing pressures at the break-in-grade section are obtained by interpolation. Shear and moment values at any location in the toe and heel of any section are computed by statics. Figure 33 shows the vertical loads involved. Direct compressive forces in footing projections and in the toe slab are computed as indicated above for floor slab steel. With the force system at a location known, steel requirements are readily ascertained. Longitudinal shear is again treated both ways.

Pavement slab steel

Longitudinal steel areas and spacings are determined at the ten points
in the pavement slab shown in Figure 46. Shear and moment values for
these locations are obtained during preliminary design at the same
time slab thicknesses are checked throughout the slab for longitudinal
shear and moment. Both LC #1 and LC #2 are investigated to obtain maxi-
mum requirements.
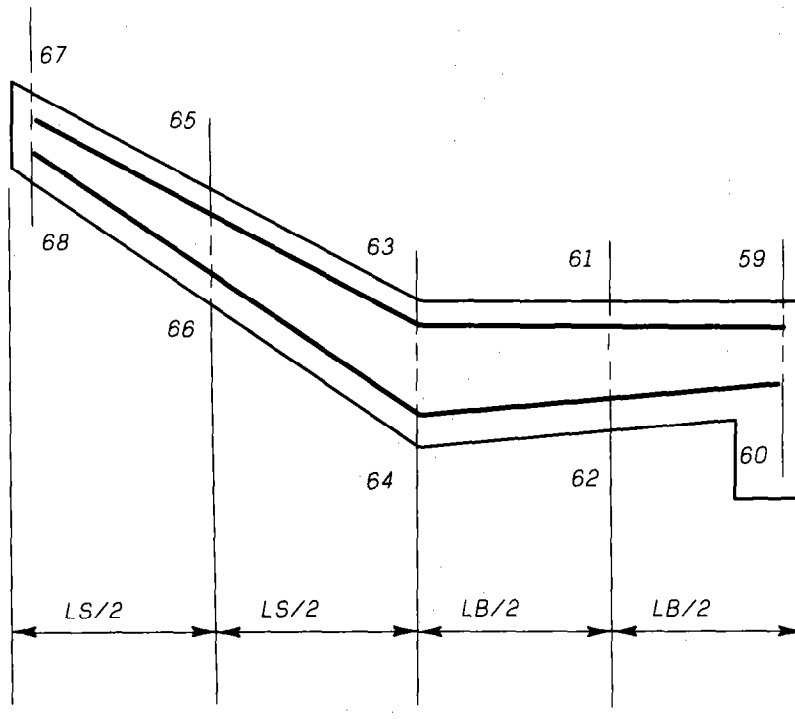
Figure 46. Pavement slab steel layout and point locations

Wingwall steel

Steel areas and spacings are determined at six points in each of three
sections in the wingwall. Figure 47 gives the location of the sections
and numbering of the points. The sections are adjacent to the articu-
lation joint and at the interior third points of the wingwall span.
Figure 48 gives the wingwall section steel layout and locates the six
points where steel requirements are evaluated.

There are two lines of principal steel in a wingwall section. These
lines are the vertical steel in the back face of the wingwall and the
top steel in the wingwall footing. Detailing must ensure that ade-
quate anchorage is provided these two lines at the junction of wing-
wall and wingwall footing. All other steel in the section is required

only in T and S amounts.

Determination of the steel requirements at point a, b, or c in any section necessitates the evaluation of the force system MZ, NZ, and VZ shown in Figure 49 where Z is the distance from the top of the section down to the point in question. Possible cases of DW, YW, and YB are illustrated from which MZ, NZ, and VZ are computed for a particular load condition. At interior sections where X > (J - DW), the water depths, YW and DW, are equal and exceed the height of the section, HSW. All five load conditions of Figure 36 are investigated to determine maximum requirements.

Figure 47. Wingwall steel point locations

Figure 48. Wingwall section steel layout

Determination of the steel requirements at point d, e, or f similarly necessitates the evaluation of the force system MZ, NZ, and VZ shown in Figure 50 where Z is the distance from the edge of the footing projection to the point in question. Sketch (A) shows a possible combination of YB, YW, and DW. Sketch (B) shows the resulting loadings and bearing pressures and indicates the summation to obtain MZ and VZ. The direct compressive force, NZ, is obtained as suggested by the next two sketches. Sketch (C) defines the resultant horizontal forces involved. Sketch (D) puts the section in horizontal equilibrium using the resultant horizontal forces and indicates the summation to obtain NZ. All five load conditions of Figure 36 are investigated.

The wingwall footing thickness required for shear is checked during these computations. Maximum shear in the footing can occur at the face of the wall or at some interior location. Shear seldom controls thickness. When it does, the thickness is incremented and the footing steel design is begun again.
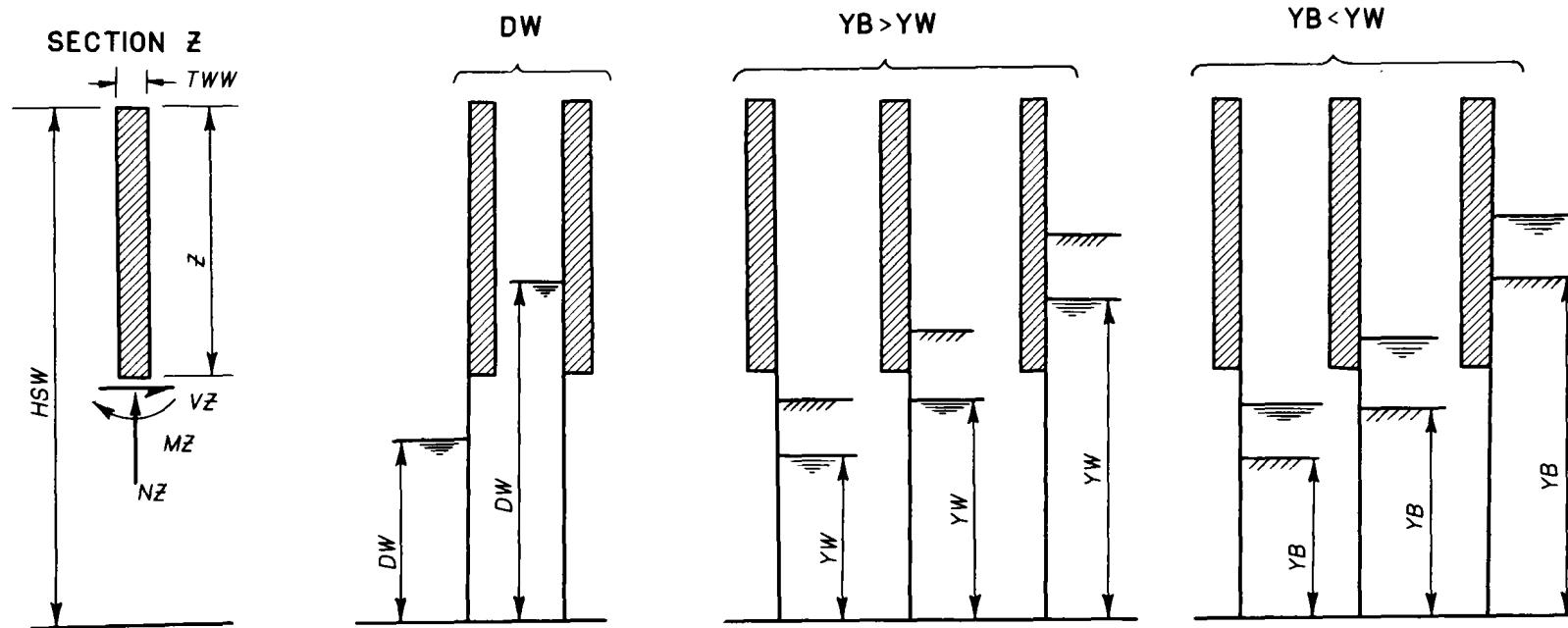
Figure 49. Determination of the force system at a point in wingwall

SEE FIGURE 39

(A)

(B)

FTG PRESS.

FTG DEAD

UPLIFT

BEARING

(C)

(D)
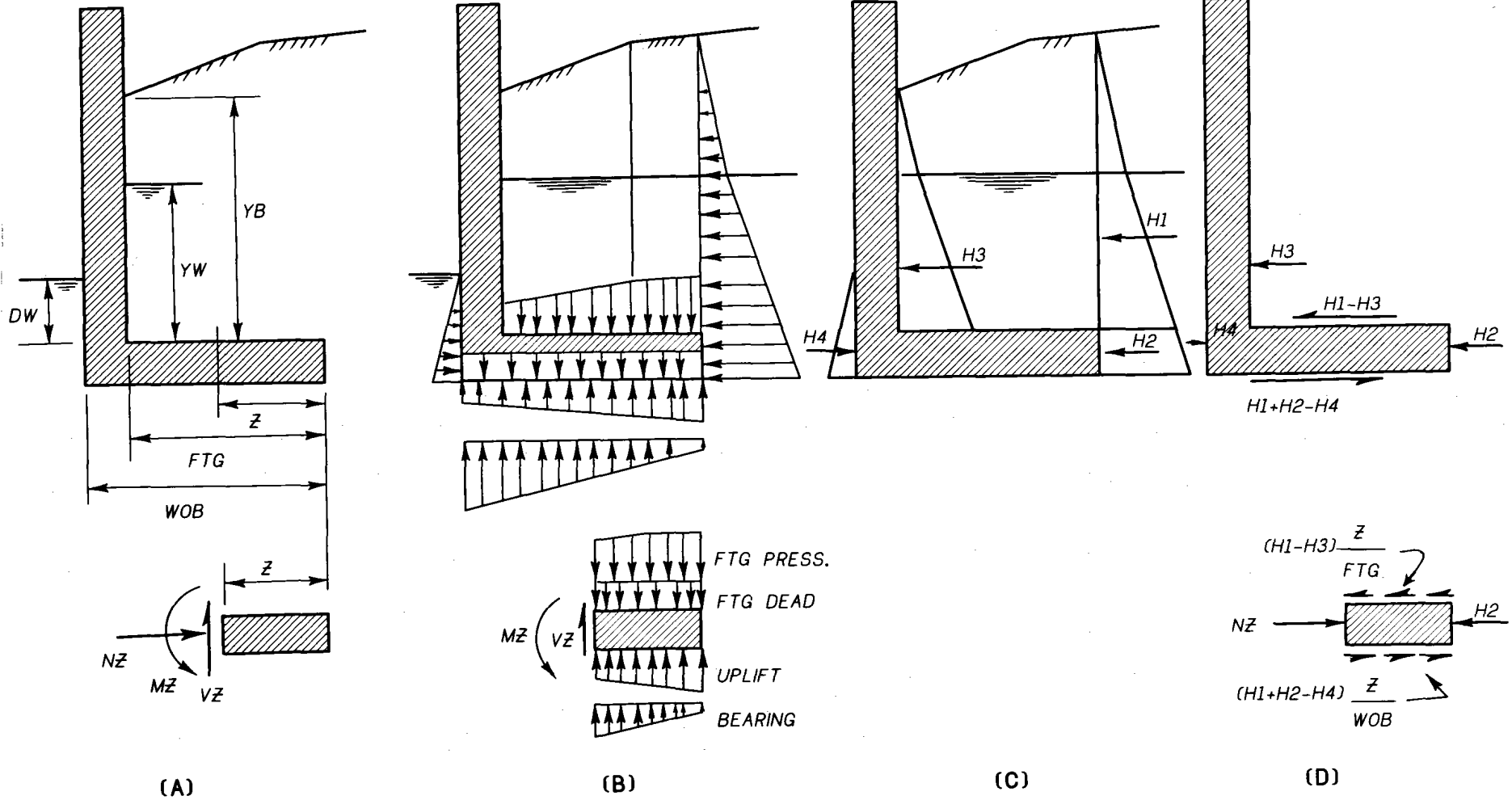
Figure 50. Determination of the force system in wingwall footing

Concrete Volumes

Concrete volumes, in cubic yards, are computed for both preliminary and detail designs. The volumes are given in two parts. The first is the volume of the basin proper, exclusive of wingwalls. The second is the volume of the wingwalls including several adjustments. These adjustments account for the mating of (1) sidewall to wingwall, (2) basin and wingwall toewalls, and (3) basin and wingwall footings.

Basin Volumes

The basin volume of each type of SAF stilling basin is readily obtained. Certain assumptions are made to facilitate computing this volume. It is assumed that the sidewalls end abruptly at the downstream end section. It is further assumed that the basin toewall ends abruptly at the outer edges of the sidewall, that is, the toewall does not extend under the basin footing projections.

The basin volume for type (A) outlets is obtained by partitioning the sidewalls and floor slab as shown by Figure 17. Component solids are prismatoids for which the volume in general is

$$V = (A_1 + 4A_m + A_2)h/6$$

where

$A_1 \equiv$ area of right section at one end of solid

$A_2 \equiv$ area of right section at other end of solid

$A_m \equiv$ area of mid-section of solid

$h \equiv$ perpendicular distance between right end sections.

The basin volume for a type (B) basin is obtained in accordance with the partitioning shown by Figure 24. Similarly, the volume of the retaining wall portion of a type (C) basin is also obtained in accordance with Figure 24, but with floor slab thickness of TSBG at the break-in-grade. The pavement slab volume of a type (C) basin follows from Figure 28, sketch (A). In calculating these volumes, the overall widths of the basin are taken as

$$WO = W + 2(TBV/12 + FTG)$$

for type (A), and also for type (C), but with W taken as 2X. Type (B) widths are

$$WOU = W + 2(TBVU/12 + FTGU)$$

$$WOD = W + 2(TBVD/12 + FTGD).$$

It should be noted the basin volumes do not include volumes of chute blocks, floor blocks, end sills, fillets on toewalls, or upstream floor joint steps. It is assumed that chute blocks, floor blocks, and end sills are dimensioned during hydraulic design and that they are subject to some shape and/or size variation. Likewise, fillet size and joint step details are subject to variation depending on designer preference.

Wingwall Volumes

The computation of the wingwall volume with its adjustments is somewhat complicated. Figure 4 shows a typical wingwall layout. First the wing-

wall volume is computed without adjustments. As with the basin proper, certain assumptions are made to facilitate computing this volume. It is assumed that the wingwall and wingwall toewall begin at the articulation joint and extend outward a span of (J-1). It is further assumed that the basin proper is without footing projections. The wingwall volume without adjustments, VWOAD, thus consists of the volumes of (1) the wingwall, (2) the wingwall toewall, and (3) the wingwall footing with its extension back to the basin sidewall. Figure 51 delineates these volumes.
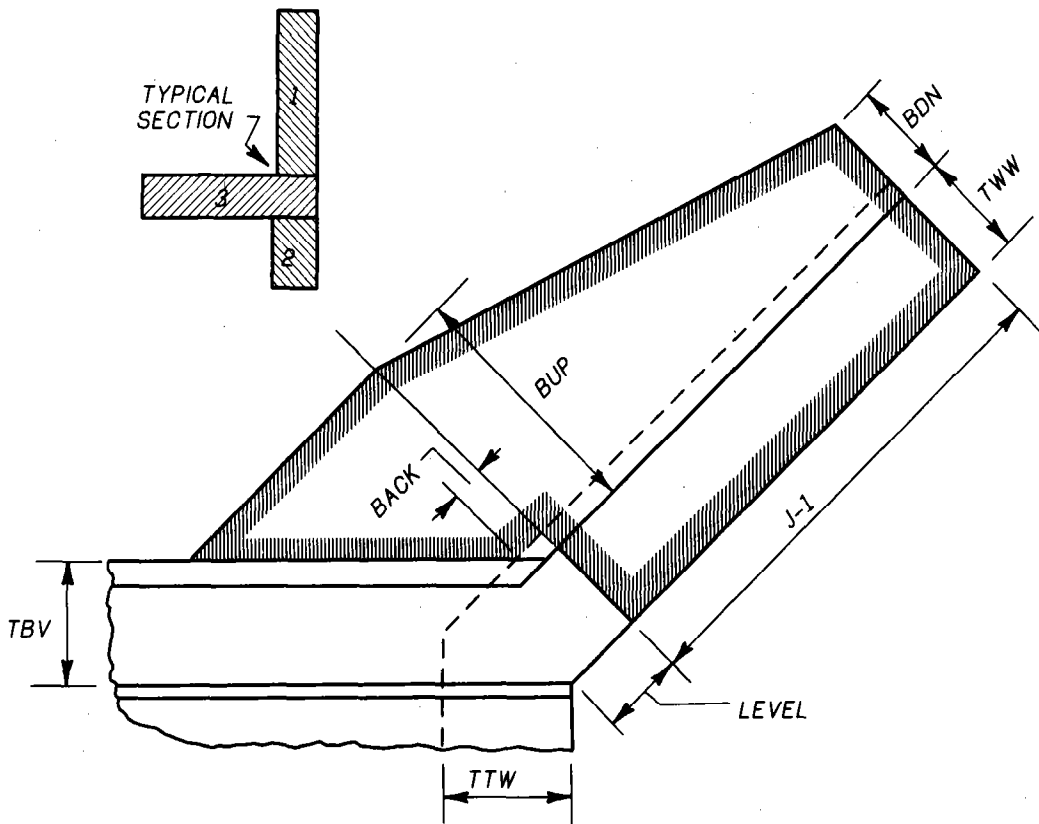
Figure 51. Wingwall volume without adjustments

The adjustments subsequently applied to the wingwall volume depend on the corner detail shown in Figures 4 and 51. The corner detail is shown to larger scale in Figure 52. The thickness of the wingwall toewall, TWT, is the larger of the thickness of the basin toewall, TTW, or the thickness of the wingwall, TWW. The level distance, LEVEL, which locates the articulation joint with respect to the corner of the sidewall, and the distance, BACK, which serves to define the wingwall footing extension back to the sidewall, are given in inches by

$$LEVEL = TBV/\sqrt{2}$$

$$BACK = TWT - LEVEL$$

when

$$TBV \leq TWW \times \sqrt{2}$$

otherwise

$$LEVEL = TBV \times \sqrt{2} - TWW$$

$$BACK = TWT - TWW$$

The former case is illustrated by Figure 51 and the upper sketch of Figure 52. The latter case is illustrated by Figure 4 and the lower sketch of Figure 52.

(A) $TBV \leq TWW \times \sqrt{2}$

(B) $TBV > TWW \times \sqrt{2}$
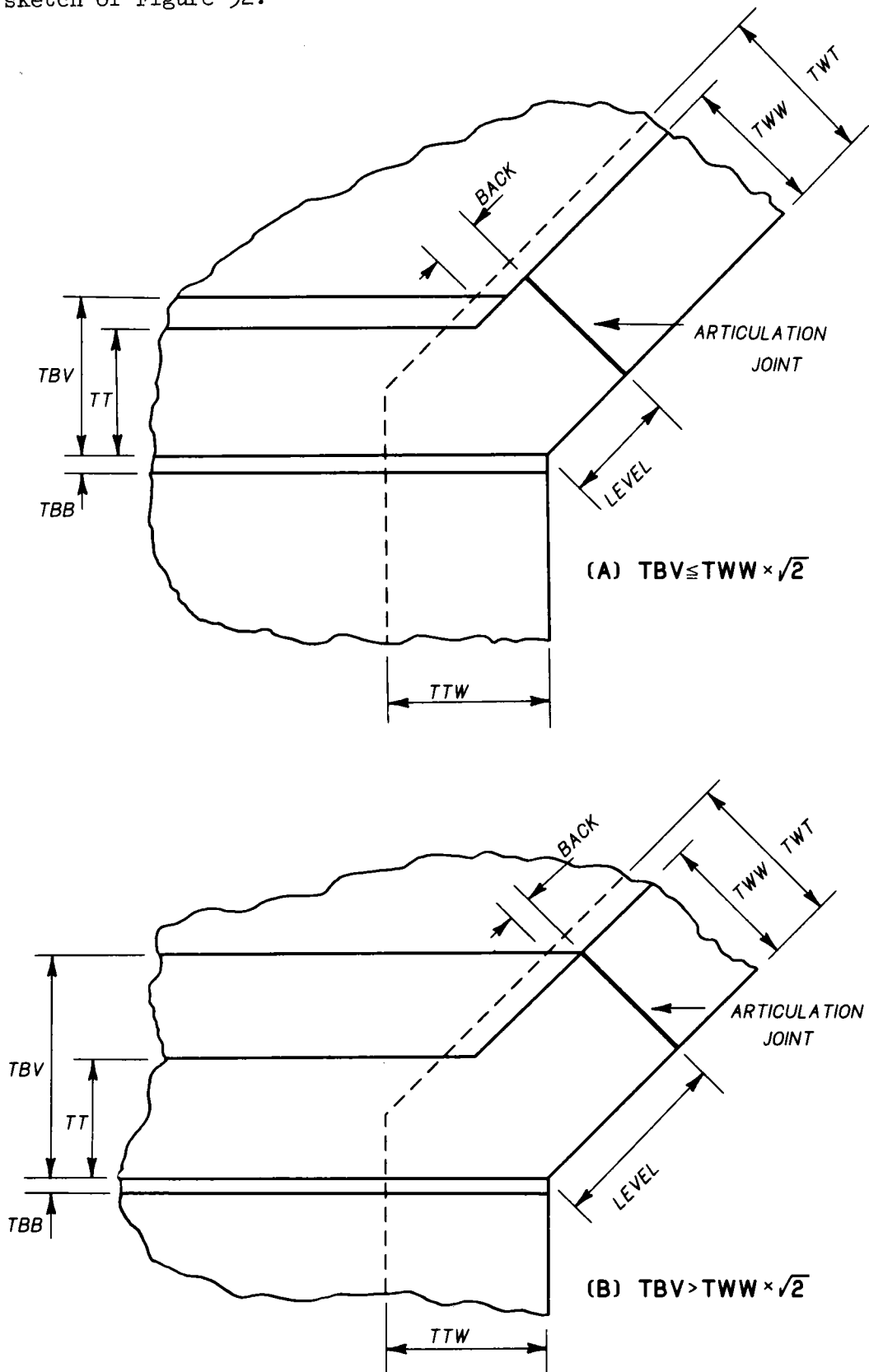
Figure 52. Corner detail, wingwall-to-sidewall

Sidewall stub adjustment. Instead of the sidewall ending abruptly at the downstream end section, the sidewall makes a 45° turn and ends at the articulation joint as is shown in Figure 52. Thus a volume correction or adjustment is necessary. Adjustments are applied herein to the wingwall volume so that relative volumes of different types of basins may be directly compared with more meaning. The sidewall stub adjustment volume, VWALL, is the difference between the sidewall volumes when the sidewall ends at the articulation joint and when the sidewall ends at the downstream end section.

Toewall stub adjustment. Instead of the basin toewall ending at the outer edges of the sidewall, the basin toewall mates with the wingwall toewall in a 45° turn as is shown in Figure 52. Thus another volume adjustment is required. The toewall stub adjustment volume, VTOE, is the difference between the volume of the basin toewall mated to the wingwall toewall (the toewall taken to the plane of the articulation joint) and the volume of the basin toewall ending at the outer edge of the sidewall.

Basin footing adjustment. Usually the basin proper will have footings. Such footings extend to the downstream end section. Thus an adjustment is necessary that will take account of any wingwall footing that is in space already occupied by the basin footing. Several configurations are possible depending on the relative values of the basin footing projection, FTG, vs the wingwall variables, WTWT, WEXT, WDES, and WPROJ shown in Figure 53. Sketch (A) illustrates these variables and also the distance, WWLB. This is the distance from the plane of the downstream end section upstream to the point where the wingwall footing extended backward would intersect the outer edge of the sidewall. The wingwall variables, in feet, are

$$WPROJ = (BACK/12 + (J - 1) + (BDN - (TWT - TWW)/12))/\sqrt{2}$$

$$WEXT = (BUP + (BACK - (TWT - TWW))/12)/\sqrt{2}$$

$$WTWT = (TWT \times \sqrt{2} - TBV)/12$$

$$WWLB = (BUP - (TBV/\sqrt{2} - TWW)/12)\sqrt{2}$$

Sketches (B) through (E) of Figure 53 indicate by shaded area, the basin footing adjustment volume that must be deducted from the wingwall volume without adjustment. Sketch (E) shows a rare but possible case where a volume indicated by the lined area must be added to the wingwall volume without adjustment. The basin footing adjustment volume, VFTG, is computed using the wingwall footing thickness, TWF. Let

$$VWING = VWOAD + VWALL + VTOE$$

then, the adjusted wingwall volume is

$$QUANT = VWING - VFTG.$$

If for any reason VFTG can not be computed, QUANT is set to zero and a message is given. For example, VFTG is not computed when
$(WWLB - LB) > FTG$. This does not mean the design is unsatisfactory. Rather, it means that some design decision is necessary concerning the layout of the wingwall footing.
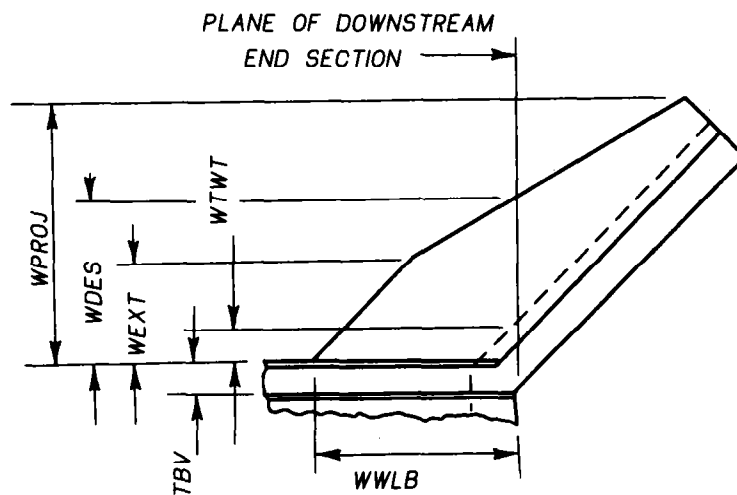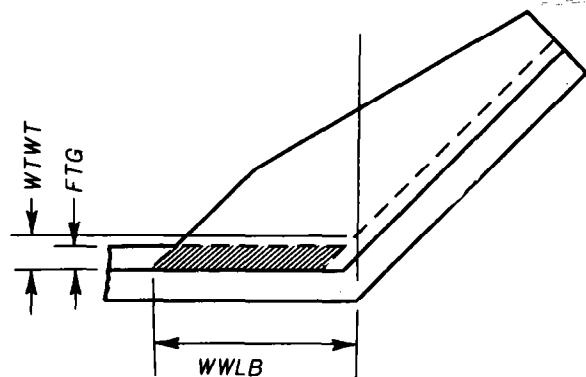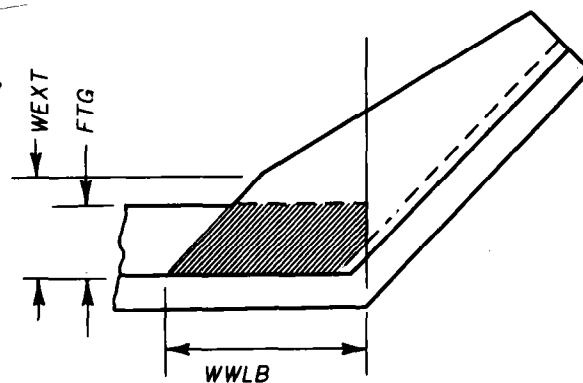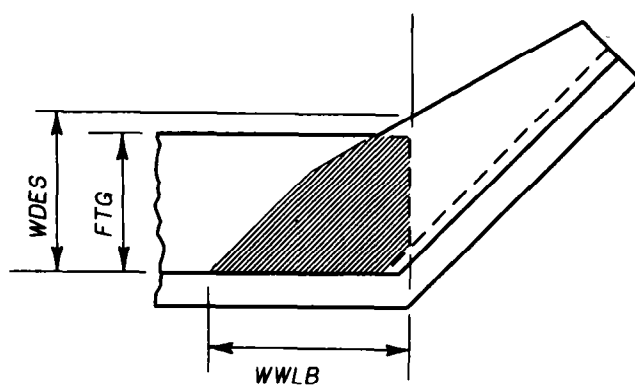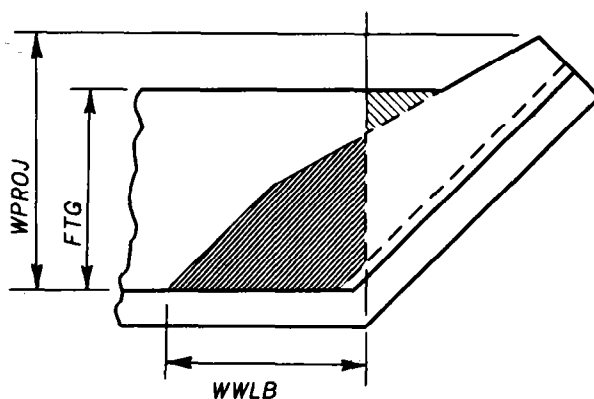
Figure 53. Basin-wingwall footing possibilities

Computer Designs

Input

Two lines of alphameric information must preceed all other data in the
input for a computer job. A given computer job may include many design
runs. From one to five lines of input data are required for each design
run. A design run is made for a particular set of design conditions
and takes one of two forms. The first form consists of three prelimin-
ary designs, one for each SAF stilling basin type, plus a preliminary
design of the wingwalls. The second form consists of the detail de-
sign of one of the basin types plus a detail design of the wingwalls.

The input data provided per design run consists essentially of values
for the primary design parameters and, if desired, values for the secon-
dary parameters. Table 2 shows the lines that may be provided per run
together with the specific design parameters contained on the first and
last three lines.

<p align="center">Table 2. Input values per design run</p>

W	J	LB	N	D1	V1	DESIGN	DFALTS
DFALT1	DFALT2	DFALT3	-	-	-	-	-
HB	HTW2	HUP2	HTW1	HUP1	-	-	-
MAXFTG	FLOATR	SLIDER	ZS	BAT	-	-	-
GM	GS	KO	CFSC	HTW	TTW	-	-

The first line contains the primary parameters, W, J, LB, N, D1, and V1
and is always required. If DESIGN = 0, the three preliminary designs
are performed. If DESIGN = 1, 2, or 3, the detail design of SAF type
(A), (B), or (C) is performed. If DFALTS = 0, all secondary parameters
are assigned default values and the next four lines must be omitted.
If DFALTS > 0, some or all secondary parameters are assigned user values
and the next line of input data must be provided.

If DFALT1 = 0, the line of input data starting with HB must be omitted.
If DFALT1 > 0, the line of input data containing values of HB through
HUP1 must be provided.

If DFALT2 = 0, the line of input data starting with MAXFTG must be omit-
ted. If DFALT2 > 0, the line of input data containing values of MAXFTG
through BAT must be provided. Similarly for DFALT3 and the line of in-
put data starting with GM.

Thus the number of lines of data that must be provided per design run
will vary depending on whether the default values are acceptable or
whether the user wishes to supply certain secondary parameter values.
Note that although various lines may be omitted, those supplied must be
complete and in the order indicated.

The two lines of alphameric data are used to provide information such as site number, watershed, state, date of design, and similar information desired by the requesting office.

Output

The output for each design run, whether preliminary designs or a detail design, repeats the two alphameric lines of input and gives the parameter values used for that run. These parameters are listed and identified at the beginning of the design.

Messages. The execution of a design run is not attempted when the computer recognizes input parameters are unacceptable. When this happens, the output references a message giving the reason the run was not executed. These messages follow.

Message No. 1
The Froude number is less than 3.0

Message No. 2
HTW2 exceeds J

Message No. 3
HUP2 exceeds HTW2

Message No. 4
HUP1 exceeds HUP2

Message No. 5
HTW1 exceeds HUP1

Message No. 6
HB exceeds J

Message No. 7
N is less than D1

Message No. 8
HTW2 is less than D1

Message No. 9
LB is less than arbitrary minimum of 2.0 ft

Message No. 10
N is more than arbitrary maximum of 0.9J

Message No. 11
HB is less than zero

Message No. 12
ZS is less than arbitrary minimum of 2.0

Sometimes an executing design can not be completed. This may occur during preliminary design or more rarely during detail design. When this happens, the output contains a short message which identifies

the basin or element involved and gives the underlying cause when possible.

Preliminary designs. Preliminary design results are listed in the order type (A), (B), (C) and wingwall, see Figure 54. Output values consist of distances, thicknesses, and concrete volumes. The units are feet, inches, and cubic yards respectively. Items may be identified by reference to various figures:

For type (A) see Figures 1 and 11

For type (B) see Figures 2 and 11

For type (C) see Figures 3, 11, and 28(A)

For wingwall see Figure 4.

Detail designs. The output for the detail design of any basin type includes several segments. The output repeats the preliminary design results. The output gives final distance and thickness values (these will often be identical to the preliminary design values). The output includes a listing of steel requirements giving required area and maximum allowable spacing in sq. in. per ft and inches. The output then provides similar detail information for the associated wingwalls.

Type (A). -- See Figure 55 for an output example. See Figures 42 and 44 for the steel locations listed.

Type (B). -- See Figure 56 for an output example. See Figures 42 and 44 for the steel locations listed.

Type (C). -- See Figure 57 for an output example. See Figures 42 and 45 for the retaining wall portion steel locations listed. See Figure 46 for the pavement slab steel locations listed.

Wingwalls. -- Wingwall detail designs are a part of Figures 55, 56, and 57. See Figures 4 and 53 for item identification. See Figures 41, 47, and 48 for the steel locations listed. The required area of the wingwall-to-basin tie is given in sq. inches. LEVEL is in inches, WPROJ and WWLB are in feet, and VWING is in cubic yards.

```
................................................................................
                            SAF  STILLING BASIN
                             STRUCTURAL DESIGN
               ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

             SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                     FOR

                EXAMPLE SPECIAL DESIGNS FOR STILLING BASIN TECHNICAL RELEASE
                     JOAN FOR ESA------------8/7/73

                       DESIGN PARAMETERS
        W = 20.00   D1   = 1.75   HTW1= 4.00   HB = 7.00   GM =110.0   MAXFTG=10.00
        J = 18.75   V1   = 50.00  HUP1= 6.00   ZS = 2.50   GS =120.0   FLOATR= 1.25
        LB= 16.75   FROUDE= 44.37 HTW2=13.50   HTW= 4.00   KO = 0.750  SLIDER= 1.10
        N =  6.75   D2   = 15.63  HUP2=11.00   TTW=12.00   BAT= 0.0    CFSC = 0.40

                       PRELIMINARY DESIGNS FOLLOW

                       TYPE (A) STILLING BASIN - TRIAL VALUES        QUANT=119.43
        LTOP= 45.45        LN=  2.51        HN=  6.27        HV=  9.37
        LBOT= 47.96        LS= 31.21        HS= 12.48
          TT= 10.00        TV= 12.50        TBB=  0.0        TBV= 15.00    TB= 15.00
         FTG=  3.00        TSUP= 13.00      TSBG= 16.00      TSDN= 16.00
                                                      ASSOCIATED WINGWALL QUANT = 27.19

                       TYPE (B) STILLING BASIN - TRIAL VALUES        QUANT=135.22
        LTOT= 46.75        LS= 30.00        HS= 12.00        HV=  9.37
          TT= 10.00        TVU= 12.50       TBB=  0.0        TBVU= 15.00   TBU= 15.00
                           TVD= 12.50                        TBVD= 15.00   TBD= 15.00
        FTGU=  4.00        TSUP= 13.00      TSBGU= 22.00
        FTGD=  4.75                         TSBGD= 22.00     TSDN= 16.00
                                                      ASSOCIATED WINGWALL QUANT= 25.70

                       TYPE (C) STILLING BASIN - TRIAL VALUES        QUANT=119.59
        LTOT= 46.75        LS= 30.00        HS= 12.00        HV=  9.37
           X= 10.00        XP=  0.0
                           TPUP= 50.00      TPBG= 88.00      TPDN= 69.00
          TT= 10.00        TV= 12.50        TBB=  0.0        TBV= 15.00    TB= 15.00
         FTG=  3.00        TSUP= 14.00      TSBG= 17.00      TSDN= 16.00
                                                      ASSOCIATED WINGWALL QUANT= 27.19

                       WINGWALL DESIGN   TRIAL VALUES
        TWW= 10.00         TWF= 10.00       BUP= 12.50       BDN=  3.50

.......................... END PRELIMINARY DESIGNS ..........................


................................................................................
                            SAF  STILLING BASIN
                             STRUCTURAL DESIGN
               ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

             SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                     FOR

                EXAMPLE SPECIAL DESIGNS FOR STILLING BASIN TECHNICAL RELEASE
                     JOAN FOR ESA------------8/7/73

                       DESIGN PARAMETERS
        W = 20.00   D1   = 1.00   HTW1= 2.00   HB = 5.00   GM =120.0   MAXFTG=10.00
        J = 12.00   V1   = 35.00  HUP1= 4.00   ZS = 3.00   GS =140.0   FLOATR= 1.50
        LB= 16.00   FROUDE= 38.04 HTW2= 8.00   HTW= 4.00   KO = 0.800  SLIDER= 1.00
        N =  4.00   D2   = 8.24   HUP2= 6.00   TTW=10.00   BAT= 0.375  CFSC = 0.35

                       PRELIMINARY DESIGNS FOLLOW

                       TYPE (A) STILLING BASIN - TRIAL VALUES        QUANT= 63.91
        LTOP= 39.35        LN=  1.26        HN=  3.79        HV=  6.00
        LBOT= 40.62        LS= 24.62        HS=  8.21
          TT= 10.00        TV= 10.00        TBB=  2.00       TBV= 10.00    TB= 12.00
         FTG=  1.00        TSUP= 11.00      TSBG= 13.00      TSDN= 13.00
                                                      ASSOCIATED WINGWALL QUANT= 12.66

                       TYPE (B) STILLING BASIN - TRIAL VALUES        QUANT= 66.83
        LTOT= 40.00        LS= 24.00        HS=  8.00        HV=  6.00
          TT= 10.00        TVU= 10.00       TBB=  2.00       TBVU= 10.00   TBU= 12.00
                           TVD= 10.00                        TBVD= 10.00   TBD= 12.00
        FTGU=  1.00        TSUP= 11.00      TSBGU= 14.00
        FTGD=  3.00                         TSBGD= 14.00     TSDN= 13.00
                                                      ASSOCIATED WINGWALL QUANT= 11.46

                       TYPE (C) STILLING BASIN - TRIAL VALUES        QUANT= 69.29
        LTOT= 40.00        LS= 24.00        HS=  8.00        HV=  6.00
           X=  9.00        XP=  2.00
                           TPUP= 24.00      TPBG= 50.00      TPDN= 37.00
          TT= 10.00        TV= 10.00        TBB=  2.00       TBV= 10.00    TB= 12.00
         FTG=  1.00        TSUP= 11.00      TSBG= 13.00      TSDN= 13.00
                                                      ASSOCIATED WINGWALL QUANT= 12.66

                       WINGWALL DESIGN - TRIAL VALUES
        TWW= 10.00         TWF= 10.00       BUP=  8.00       BDN=  3.50

.......................... END PRELIMINARY DESIGNS ..........................
```

Figure 54. Computer output, preliminary designs

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==============================================================================
                        SAF  STILLING BASIN
                       STRUCTURAL DESIGN
            ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

           SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                FOR

            EXAMPLE SPECIAL DESIGNS FOR STILLING BASIN TECHNICAL RELEASE
            JOAN FOR ESA - - - - - - - - - - 3/18/74

                     DESIGN PARAMETERS
     W = 40.00   D1  =  1.00   HTW1= 4.00   HB = 2.67   GM =105.0   MAXFTG= 8.00
     J = 12.00   V1  = 45.00   HUP1= 4.00   ZS = 3.00   GS =120.0   FLOATR= 1.20
     LB= 10.00   FROUDE= 62.89 HTW2= 9.00   HTW= 4.00   KO =  0.667  SLIDER= 1.00
     V = 6.00    D2  = 10.73   HUP2= 5.00   TTW=10.00   BAT=  0.250  CFSC = 0.35

                     DESIGN OF SPECIFIED TYPE SAF FOLLOWS

               TYPE (A) STILLING BASIN - TRIAL VALUES          QUANT= 86.69
     LTOP= 27.03        LN=  1.90      HN=  5.69      HV=  6.00
     LBOT= 28.92        LS= 18.92      HS=  6.31
       TT= 10.00        TV= 10.00     TBB=  2.00      TBV= 10.00    TB= 12.00
      FTG=  1.00      TSUP= 15.00    TSBG= 18.00     TSDN= 14.00

               TYPE (A) STILLING BASIN - DETAIL DESIGN         QUANT= 86.69
       TT= 10.00        TV= 10.00     TBB=  2.00      TBV= 10.00    TB= 12.00
      FTG=  1.00      TSUP= 15.00    TSBG= 18.00     TSDN= 14.00

                     STEEL REQUIREMENTS
     WALL
     A( 1)=  0.24     S( 1)= 18.00              A( 6)=  0.24     S( 6)= 18.00
     A( 2)=  0.24     S( 2)= 18.00              A( 7)=  0.24     S( 7)= 18.00
     A( 3)=  0.24     S( 3)= 18.00              A( 8)=  0.24     S( 8)= 18.00
     A( 4)=  0.27     S( 4)= 18.00              A( 9)=  0.27     S( 9)= 18.00
     A( 5)=  0.58     S( 5)= 18.00              A(10)=  0.58     S(10)= 18.00
                                               A( 0)=  0.49     S( 0)= 18.00

     BASE
     SECTION AT DOWNSTREAM END
     A(11)=  0.17     S(11)= 18.00              A(17)=  0.45     S(17)= 18.00
     A(12)=  0.17     S(12)= 18.00              A(18)=  0.17     S(18)= 18.00
     A(13)=  0.17     S(13)= 18.00              A(19)=  0.95     S(19)= 18.00
     A(14)=  0.17     S(14)= 18.00              A(20)=  1.16     S(20)= 18.00
     A(15)=  0.17     S(15)= 18.00              A(21)=  1.27     S(21)= 18.00
     A(16)=  0.17     S(16)= 18.00              A(22)=  1.69     S(22)= 18.00
     SECTION AT BREAK-IN-GRADE
     A(23)=  0.22     S(23)= 18.00              A(29)=  0.43     S(29)= 18.00
     A(24)=  0.22     S(24)= 18.00              A(30)=  0.22     S(30)= 18.00
     A(25)=  0.22     S(25)= 18.00              A(31)=  1.79     S(31)= 18.00
     A(26)=  0.22     S(26)= 18.00              A(32)=  0.22     S(32)= 18.00
     A(27)=  0.22     S(27)= 18.00              A(33)=  2.48     S(33)= 18.00
     A(28)=  0.22     S(28)= 18.00              A(34)=  0.22     S(34)= 18.00
     SECTION AT UPSTREAM END
     A(47)=  0.18     S(47)= 18.00              A(53)=  0.36     S(53)= 18.00
     A(48)=  0.18     S(48)= 18.00              A(54)=  0.18     S(54)= 18.00
     A(49)=  0.18     S(49)= 18.00              A(55)=  0.36     S(55)= 18.00
     A(50)=  0.18     S(50)= 18.00              A(56)=  1.08     S(56)= 18.00
     A(51)=  0.18     S(51)= 18.00              A(57)=  0.45     S(57)= 18.00
     A(52)=  0.18     S(52)= 18.00              A(58)=  1.40     S(58)= 18.00

                     WINGWALL DESIGN - TRIAL VALUES
     TWW= 10.00       TWF= 10.00      BUP=  7.50      BDN=  1.50

                     WINGWALL DESIGN - DETAIL DESIGN           QUANT= 11.60
     TWW= 10.00       TWF= 10.00      BUP=  7.50      BDN=  1.50
     LEVEL=  7.07    WPROJ=  9.01   WWLB=10.95     VWING= 12.25

                     STEEL REQUIREMENTS
     AREA OF TIE=  0.17
     SECTION AT ARTICULATION JOINT
     A( 1)=  0.24     S( 1)= 18.00              A( 4)=  0.12     S( 4)= 18.00
     A( 2)=  0.24     S( 2)= 18.00              A( 5)=  0.20     S( 5)= 18.00
     A( 3)=  0.12     S( 3)= 18.00              A( 6)=  0.18     S( 6)= 18.00
     SECTION AT UPPER THIRD POINT
     A( 7)=  0.24     S( 7)= 18.00              A(10)=  0.12     S(10)= 18.00
     A( 8)=  0.24     S( 8)= 18.00              A(11)=  0.12     S(11)= 18.00
     A( 9)=  0.12     S( 9)= 18.00              A(12)=  0.12     S(12)= 18.00
     SECTION AT LOWER THIRD POINT
     A(13)=  0.24     S(13)= 18.00              A(16)=  0.12     S(16)= 18.00
     A(14)=  0.12     S(14)= 18.00              A917)=  0.12     S(17)= 18.00
     A(15)=  0.12     S(15)= 18.00              A(18)=  0.12     S(18)= 18.00

     =========================== END DETAIL DESIGN  ============================
```

Figure 55. Computer output, type (A) detail design

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================================================================================
                          SAF  STILLING BASIN
                           STRUCTURAL DESIGN
              ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

             SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                    FOR

                 EXAMPLE SPECIAL DESIGNS FOR STILLING BASIN TECHNICAL RELEASE
                 JOAN FOR ESA - - - - - - - - - - 3/18/74

                     DESIGN PARAMETERS
        W = 20.00  D1   =  2.00  HTW1= 0.0    HB =10.00  GM =120.0   MAXFTG=10.00
        J = 20.00  V1   = 36.00  HUP1= 5.86   ZS = 3.00  GS =140.0   FLOATR= 1.50
        LB= 24.00  FROUDE= 20.12 HTW2=11.73   HTW= 4.00  KO =  0.800 SLIDER= 1.00
        N = 14.00  D2   = 11.73  HUP2=11.73   TTW=10.00  RAT=  0.375 CFSC = 0.35

                     DESIGN OF SPECIFIED TYPE SAF FOLLOWS

                  TYPE (B) STILLING BASIN - TRIAL VALUES          QFANT=150.36
        LTOT= 42.00      LS= 18.00        HS=  6.00         HV= 14.00
           TT= 10.00    TVU= 16.30       TBB=  2.00        TBVU= 19.00   TBU= 21.00
                        TVD= 14.90                         TBVD= 17.00   TBD= 19.00
        FTGU=  3.50    TSUP= 18.00     TSBGU= 22.00
        FTGD=  4.75                    TSBGD= 20.00        TSDN= 20.00

                  TYPE (B) STILLING BASIN - DETAIL DESIGN         QUANT=150.36
           TT= 10.00    TVU= 16.30       TBB=  2.00        TBVU= 19.00   TBU= 21.00
                        TVD= 14.90                         TBVD= 17.00   TBD= 19.00
        FTGU=  3.50    TSUP= 18.00     TSBGU= 22.00
        FTGD=  4.75                    TSBGD= 20.00        TSDN= 20.00

                          STEEL REQUIREMENTS
        WALL
        A( 1)=  0.24     S( 1)= 18.00          A( 6)=  0.24     S( 6)= 18.00
        A( 2)=  0.30     S( 2)= 18.00          A( 7)=  0.30     S( 7)= 18.00
        A( 3)=  2.16     S( 3)= 14.00          A( 8)=  0.76     S( 8)= 18.00
        A( 4)=  2.27     S( 4)= 13.85          A( 9)=  1.61     S( 9)= 16.36
        A( 5)=  2.47     S( 5)= 13.54          A(10)=  2.82     S(10)= 12.07
        BASE
        SECTION AT DOWNSTREAM END
        A(11)=  0.24     S(11)= 18.00          A(17)=  0.48     S(17)= 18.00
        A(12)=  0.24     S(12)= 18.00          A(18)=  0.24     S(18)= 18.00
        A(13)=  0.24     S(13)= 18.00          A(19)=  0.48     S(19)= 18.00
        A(14)=  0.24     S(14)= 18.00          A(20)=  0.24     S(20)= 18.00
        A(15)=  0.24     S(15)= 18.00          A(21)=  0.73     S(21)= 18.00
        A(16)=  0.24     S(16)= 18.00          A(22)=  0.24     S(22)= 18.00
        SECTION AT DOWNSTREAM SIDE OF BREAK-IN-GRADE
        A(23)=  0.24     S(23)= 18.00          A(29)=  0.48     S(29)= 18.00
        A(24)=  0.24     S(24)= 18.00          A(30)=  1.90     S(30)= 18.00
        A(25)=  0.24     S(25)= 18.00          A(31)=  0.48     S(31)= 18.00
        A(26)=  0.24     S(26)= 18.00          A(32)=  0.78     S(32)= 18.00
        A(27)=  0.45     S(27)= 18.00          A(33)=  0.48     S(33)= 18.00
        A(28)=  0.24     S(28)= 18.00          A(34)=  0.41     S(34)= 18.00
        SECTION AT UPSTREAM SIDE OF BREAK-IN-GRADE
        A(35)=  0.26     S(35)= 18.00          A(41)=  0.53     S(41)= 18.00
        A(36)=  0.26     S(36)= 18.00          A(42)=  1.92     S(42)= 18.00
        A(37)=  0.26     S(37)= 18.00          A(43)=  0.53     S(43)= 18.00
        A(38)=  0.26     S(38)= 18.00          A(44)=  0.97     S(44)= 18.00
        A(39)=  0.26     S(39)= 18.00          A(45)=  0.53     S(45)= 18.00
        A(40)=  0.26     S(40)= 18.00          A(46)=  0.64     S(46)= 18.00
        SECTION AT UPSTREAM END
        A(47)=  0.22     S(47)= 18.00          A(53)=  0.43     S(53)= 18.00
        A(48)=  0.22     S(48)= 18.00          A(54)=  1.45     S(54)= 18.00
        A(49)=  0.22     S(49)= 18.00          A(55)=  0.43     S(55)= 18.00
        A(50)=  0.22     S(50)= 18.00          A(56)=  0.56     S(56)= 18.00
        A(51)=  0.23     S(51)= 18.00          A(57)=  0.43     S(57)= 18.00
        A(52)=  0.22     S(52)= 18.00          A(58)=  0.28     S(58)= 18.00

                     WINGWALL DESIGN - TRIAL VALUES
          TWW= 12.00        TWF= 16.00       RUP= 15.00        RDN=  6.75

                     WINGWALL DESIGN - DETAIL DESIGN             QUANT= 44.01
          TWW= 12.00        TWF= 16.00       RUP= 15.00        RDN=  6.75
        LEVEL= 12.04     WPROJ= 18.21      WWLB= 21.21       VWING= 52.84

                          STEEL REQUIREMENTS
        AREA OF TIE=  3.24
        SECTION AT ARTICULATION JOINT
        A( 1)=  0.29     S( 1)= 18.00          A( 4)=  0.58     S( 4)= 18.00
        A( 2)=  0.14     S( 2)= 18.00          A( 5)=  1.75     S( 5)= 18.00
        A( 3)=  1.17     S( 3)= 17.99          A( 6)=  2.39     S( 6)= 18.00
        SECTION AT UPPER THIRD POINT
        A( 7)=  0.29     S( 7)= 18.00          A(10)=  0.34     S(10)= 18.00
        A( 8)=  0.14     S( 8)= 18.00          A(11)=  1.11     S(11)= 18.00
        A( 9)=  0.35     S( 9)= 18.00          A(12)=  1.58     S(12)= 18.00
        SECTION AT LOWER THIRD POINT
        A(13)=  0.29     S(13)= 18.00          A(16)=  0.19     S(16)= 18.00
        A(14)=  0.14     S(14)= 18.00          A(17)=  0.51     S(17)= 18.00
        A(15)=  0.14     S(15)= 18.00          A(18)=  0.75     S(18)= 18.00

        ========================= END DETAIL DESIGN ==========================
```

Figure 56. Computer output, type (B) detail design

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------------------------------------------------------------------------------
                           SAF  STILLING BASIN
                            STRUCTURAL DESIGN
              ELASTIC ANALYSIS AND WORKING STRESS DESIGN ARE USED

           SPECIAL DESIGN PREPARED BY THE DESIGN UNIT AT HYATTSVILLE, MD.
                                    FOR

            EXAMPLE SPECIAL DESIGNS FOR STILLING BASIN TECHNICAL RELEASE
            JOAN FOR ESA------------8/7/73

                     DESIGN PARAMETERS
   W = 32.00    D1   =  2.00   HTW1 = 0.0     HB  = 8.00   GM =120.0    MAXFTG=16.00
   J = 18.00    V1   = 36.00   HUP1 = 0.0     ZS  = 3.00   GS =140.0    FLOATR= 1.50
   LB= 16.00    FROUDE= 20.12  HTW2=11.73     HTW= 4.00    KO =  0.800  SLIDER= 1.00
   N =  6.00    D2   = 11.73   HUP2= 7.00     TTW=10.00    BAT= 0.375   CFSC  = 0.35

                    DESIGN OF SPECIFIED TYPE SAF FOLLOWS

                  TYPE (C) STILLING BASIN - TRIAL VALUES       QUANT=131.51
   LTOT= 52.00        LS= 36.00        HS= 12.00        HV=  9.00
      X= 12.00        XP=  8.00
                    TPUP= 14.00      TPBG= 20.00      TPDN= 17.00
   TT= 10.00          TV= 10.50       TBB=  3.00       TBV= 11.00      TB= 14.00
   FTG=  0.0        TSUP= 12.00      TSBG= 15.00      TSDN= 15.00

                  TYPE (C) STILLING BASIN - DETAIL DESIGN       QUANT=133.59
      X= 12.00        XP=  8.00
                    TPUP= 14.00      TPBG= 20.00      TPDN= 17.00
   TT= 10.00          TV= 10.50       TBB=  3.00       TBV= 11.00      TB= 14.00
   FTG=  0.0        TSUP= 12.00      TSBG= 16.00      TSDN= 15.00

                    STEEL REQUIREMENTS
WALL
A( 1)=  0.24      S( 1)= 18.00              A( 6)=  0.24      S( 6)= 18.00
A( 2)=  0.24      S( 2)= 18.00              A( 7)=  0.24      S( 7)= 18.00
A( 3)=  0.26      S( 3)= 18.00              A( 8)=  0.25      S( 8)= 18.00
A( 4)=  0.74      S( 4)= 18.00              A( 9)=  0.18      S( 9)= 18.00
A( 5)=  1.76      S( 5)= 14.44              A(10)=  1.76      S(10)= 14.44
                                            A( 0)=  0.46      S( 0)= 18.00
BASE
SECTION AT DOWNSTREAM END
A(11)=  0.0       S(11)= 18.00              A(17)=  0.41      S(17)= 18.00
A(12)=  0.0       S(12)= 18.00              A(18)=  0.84      S(18)= 18.00
A(13)=  0.0       S(13)= 18.00              A(19)=  0.36      S(19)= 18.00
A(14)=  0.0       S(14)= 18.00              A(20)=  0.18      S(20)= 18.00
A(15)=  0.0       S(15)= 18.00              A(21)=  0.36      S(21)= 18.00
A(16)=  0.0       S(16)= 18.00              A(22)=  0.18      S(22)= 18.00
SECTION AT BREAK-IN-GRADE
A(23)=  0.0       S(23)= 18.00              A(29)=  0.38      S(29)= 18.00
A(24)=  0.0       S(24)= 18.00              A(30)=  1.64      S(30)= 18.00
A(25)=  0.0       S(25)= 18.00              A(31)=  0.38      S(31)= 18.00
A(26)=  0.0       S(26)= 18.00              A(32)=  0.26      S(32)= 18.00
A(27)=  0.0       S(27)= 18.00              A(33)=  0.38      S(33)= 18.00
A(28)=  0.0       S(28)= 18.00              A(34)=  0.19      S(34)= 18.00
SECTION AT UPSTREAM END
A(47)=  0.0       S(47)= 18.00              A(53)=  0.29      S(53)= 18.00
A(48)=  0.0       S(48)= 18.00              A(54)=  0.56      S(54)= 18.00
A(49)=  0.0       S(49)= 18.00              A(55)=  0.29      S(55)= 18.00
A(50)=  0.0       S(50)= 18.00              A(56)=  0.14      S(56)= 18.00
A(51)=  0.0       S(51)= 18.00              A(57)=  0.29      S(57)= 18.00
A(52)=  0.0       S(52)= 18.00              A(58)=  0.14      S(58)= 18.00
PAVEMENT SLAB
A(59)=  0.41      S(59)= 18.00              A(60)=  0.20      S(60)= 18.00
A(61)=  0.44      S(61)= 18.00              A(62)=  0.22      S(62)= 18.00
A(63)=  0.86      S(63)= 18.00              A(64)=  0.24      S(64)= 18.00
A(65)=  0.58      S(65)= 18.00              A(66)=  0.20      S(66)= 18.00
A(67)=  0.34      S(67)= 18.00              A(68)=  0.17      S(68)= 18.00

               WINGWALL DESIGN - TRIAL VALUES
   TWW = 10.00       TWF= 11.00      BUP = 10.50        BDN=  6.00

               WINGWALL DESIGN - DETAIL DESIGN                QUANT= 27.92
   TWW= 10.00        TWF= 11.00      BUP= 10.50        BDN=  6.00
   LEVEL=  7.78    WPROJ= 16.39     WWLB= 15.11        VWING= 27.92

                    STEEL REQUIREMENTS
AREA OF TIE=  1.99
SECTION AT ARTICULATION JOINT
A( 1)=  0.24      S( 1)= 18.00              A( 4)=  0.39      S( 4)= 18.00
A( 2)=  0.12      S( 2)= 18.00              A( 5)=  1.15      S( 5)= 18.00
A( 3)=  0.66      S( 3)= 18.00              A( 6)=  1.52      S( 6)= 18.00
SECTION AT UPPER THIRD POINT
A( 7)=  0.24      S( 7)= 18.00              A(10)=  0.25      S(10)= 18.00
A( 8)=  0.12      S( 8)= 18.00              A(11)=  0.78      S(11)= 18.00
A( 9)=  0.20      S( 9)= 18.00              A(12)=  1.08      S(12)= 18.00
SECTION AT LOWER THIRD POINT
A(13)=  0.24      S(13)= 18.00              A(16)=  0.13      S(16)= 18.00
A(14)=  0.12      S(14)= 18.00              A(17)=  0.35      S(17)= 18.00
A(15)=  0.12      S(15)= 18.00              A(18)=  0.50      S(18)= 18.00

-------------------------- END DETAIL DESIGN ---------------------------
```

Figure 57. Computer output, type (C) detail design

Appendix

Toewall Thickness and Steel for SAF Stilling Basins

The thickness of the basin toewall, TTW, and the depth of the toewall, HTW, are secondary parameters whose default values are 10.0 inches and 4.0 feet, respectively. Occasionally it may be desirable to increase one or both of these values. The vertical steel in the front face of the toewall must satisfy T and S requirements. It must also be able to resist the cantilever bending that might be induced by passive resistance of the channel material downstream of the toewall.
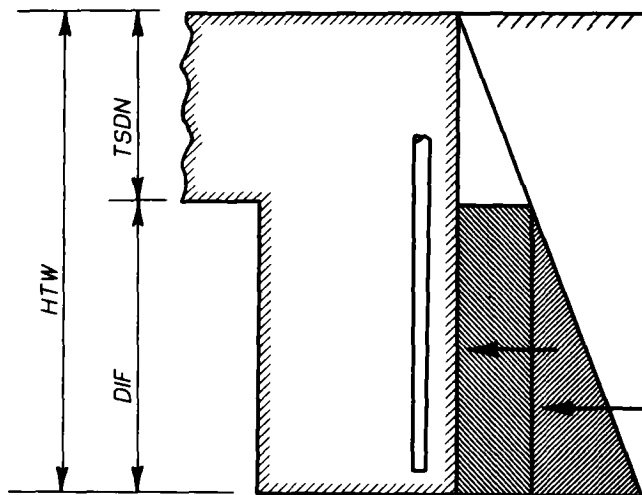
The thickness, TTW, and required vertical steel may be determined from the following analysis. Let

$KP \equiv$ passive lateral earth pressure ratio

$DIF = HTW - TSDN/12$, in ft

$V \equiv$ shear at face of support, in lbs per ft

$M \equiv$ moment at face of support, in ft lbs per ft

other nomenclature as previously defined.

Assume passive earth pressure against the downstream side of the toewall and zero earth pressure against the upstream side. Neglect water pressures on both sides and use moist unit soil weight. Then

$V = KP \times GM \times DIF \times (TSDN/12 + DIF/2)$

$M = KP \times GM \times DIF \times (TSDN/24 + DIF/3) \times DIF$

The minimum thicknesses, in inches, for shear and moment are

$TS = V/840. + 2.5$

$TM = (0.003683 \times M)^{1/2} + 2.5$

With TTW selected, the maximum steel spacing and minimum steel areas are

$$S = 10015 \times (TTW - 2.5)/V \le 18.$$

$$A \approx 0.0006 \times M/(0.88 \times (TTW - 2.5)) \ge 0.024 \times TTW$$

at the critical section.

On taking, KP = 2.0 and GM = 120. pcf, analyses show that TTW = 10.0 inches provides adequate strength for all HTW ≤ 6.0 ft. However, for the higher DIF values, required steel becomes excessive. An alternative approach is to select TTW so that steel required for T and S also satisfies strength requirements. The accompanying table accomplishes this by listing the minimum TTW for various combinations of HTW and TSDN.

Minimum TTW for which T & S steel also satisfies strength requirements							
TSDN inches	HTW, feet						
	3.0	3.5	4.0	4.5	5.0	5.5	6.0
10	10	10	12	14	16	20	22
16	10	10	10	14	16	18	20
20	10	10	10	12	14	16	20
24	10	10	10	12	14	16	18
28	10	10	10	10	12	14	18
32	10	10	10	10	12	14	16
36	--	10	10	10	10	12	14
40	--	10	10	10	10	10	14
44	--	--	10	10	10	10	12
48	--	--	--	10	10	10	10
KP = 2.0 GM = 120.pcf A for T & S = 0.024 x TTW							